ACRP

REPORT 37

AIRPORT
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Guidebook for Planning and Implementing Automated People Mover Systems at Airports

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

ACRP REPORT 37

Guidebook for Planning and Implementing Automated People Mover Systems at Airports

LEA+ELLIOTT
Dulles, Virginia

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

The need for ACRP was identified in *TRB Special Report 272: Airport Research Needs: Cooperative Solutions* in 2003, based on a study sponsored by the Federal Aviation Administration (FAA). The ACRP carries out applied research on problems that are shared by airport operating agencies and are not being adequately addressed by existing federal research programs. It is modeled after the successful National Cooperative Highway Research Program and Transit Cooperative Research Program. The ACRP undertakes research and other technical activities in a variety of airport subject areas, including design, construction, maintenance, operations, safety, security, policy, planning, human resources, and administration. The ACRP provides a forum where airport operators can cooperatively address common operational problems.

The ACRP was authorized in December 2003 as part of the Vision 100-Century of Aviation Reauthorization Act. The primary participants in the ACRP are (1) an independent governing board, the ACRP Oversight Committee (AOC), appointed by the Secretary of the U.S. Department of Transportation with representation from airport operating agencies, other stakeholders, and relevant industry organizations such as the Airports Council International-North America (ACI-NA), the American Association of Airport Executives (AAAE), the National Association of State Aviation Officials (NASAO), and the Air Transport Association (ATA) as vital links to the airport community; (2) the TRB as program manager and secretariat for the governing board; and (3) the FAA as program sponsor. In October 2005, the FAA executed a contract with the National Academies formally initiating the program.

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Primary emphasis is placed on disseminating ACRP results to the intended end-users of the research: airport operating agencies, service providers, and suppliers. The ACRP produces a series of research reports for use by airport operators, local agencies, the FAA, and other interested parties, and industry associations may arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by airport-industry practitioners.

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FOREWORD

By Lawrence D. Goldstein
Staff Officer
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ACRP Report 37 is a guidebook for planning and developing automated people mover (APM) systems at airports. This report, directed primarily at airport planners, designers, and operators, encompasses a wide range of topics describing the planning and decision-making process, alternative system infrastructure and technologies, evaluation techniques and strategies, operation and maintenance requirements, coordination and procurement requirements, and other important planning and development issues. For any given topic, the report addresses key issues in multiple chapters and from multiple perspectives. In addition, Appendix A presents two theoretical examples using specific system characteristics, and Appendix E describes components of simulation models used to facilitate the pre-design phase of the overall system planning process.

Airports are constantly struggling to meet increasing demand with greater efficiency, using available land area to increase capacity without having to expand the overall facility footprint. One significant contributor to efficient use of airport property that has emerged over the past 40 years is the APM—a fully automated transport system that allows development of remote terminals and other facilities that would normally be too distant from the main terminal for passengers to navigate within limited transfer and connecting times.

The process of planning and implementing an APM is complex and the infrastructure and equipment expensive. *ACRP Report 37* helps to address this problem by bringing together a detailed description of experience gained in previously completed systems while outlining effective planning and implementation strategies for developing new systems.

The guidebook includes an interactive CD that contains a database of detailed characteristics of the 44 existing APM systems. Using this database, planners and designers can evaluate specific options appropriate for new projects by comparing similar situations already in operation. How the guidebook user applies the findings will vary with their particular role at the airport. For example, airport planners can adapt and apply the APM planning process by drawing on information presented in Chapters 5 and 8, and in Appendix A (theoretical examples). Airport designers can identify APM design information found in Chapter 8 and in Appendix A and distribute this information to system designers at their particular airport. Airport contracts staff can use the procurement information provided in Chapter 10 and adapt that information to the specific requirements of their airport's procurement regulations. Airport operations personnel can apply the information found in Chapter 11 to help determine the most appropriate operation and maintenance approach for their specific airport. In all cases, the user is reminded that APM systems are complex in nature, and that their interface with other airport facilities presents unique challenges incurring significant cost and schedule risk.

The guidebook also presents new findings drawn from the combined evaluation of older systems as well as new systems that have recently opened at Atlanta (landside) and Washington Dulles (airside). These findings include a discussion (Appendix B) of the relationship between system length and alignment configuration, an analysis of the relationship between airport gates and airside passenger conveyance technology (Chapter 3, section 2), and a description of prospective and emerging APM components for possible future implementation (Chapter 4, section 4). Through all of these various sections, the guidebook represents a comprehensive resource for planning, design, evaluation, operation, and implementation of one of the most critical elements in long-range airport planning.

CONTENTS

SUMMARY

Guidebook for Planning and Implementing Automated People Mover Systems at Airports

This report presents draft guidebook research and findings for Airport Cooperative Research Program (ACRP) Project 03-06. The objective of this project is to provide a comprehensive guidebook for airport staff at all levels for planning and implementing automated people mover (APM) systems at airports.

The development of this guidebook is premised on the fact that with the continued growth in air travel, airports have increased in size and complexity, but the increased distances between activity centers have made them less walkable. The implementation of APMs, however, has allowed both passengers and employees, along with their luggage, wheelchairs, and other accessories, to travel long distances quickly and efficiently. Due to the time sensitivity of air travel, many airports have recognized the importance of passenger mobility and have implemented these APM systems.

APMs are fully automated and driverless transit systems that operate on fixed guideways in exclusive rights-of-way. They are not subject to congestion or interference from other types of traffic. An APM system is a combination of interrelated subsystems and elements designed to operate as a cohesive entity that provides safe, reliable, and efficient passenger transport. A full description of the APM technology, including the subsystems that comprise it, is provided in Chapter 4.

The findings of the guidebook can be summarized as follows:

- Developed initially for urban use, APMs have primarily been implemented at major airports around the world. Ease of boarding and capacity flexibility are key reasons the technology has been implemented at 44 airports to date.
- Airside APMs have allowed airports to expand in terms of distance between facilities and the numbers of aircraft gates while still maintaining service thresholds. This has contributed to the success of large airline hubbing operations.
- Landside APMs have reduced airport roadway congestion and emissions and have enabled large-scale airline hubbing operations (connecting separate landside terminals) and convenient connections to landside facilities such as parking and rental car facilities and ground transport centers.

With additional APMs opening in late 2009 and early 2010, it is clear that APMs continue to be an appropriate passenger conveyance mode for airports. Looking to the future, there are areas of research that would benefit the airport planner with respect APMs, including:

- Sustainable planning practices for new and existing APM systems, and
- Incorporation of the latest advances of the automated conveyance technology personal rapid transit (PRT) into the planning and implementation of APMs.

The guidebook also includes an interactive CD that contains a database of detailed characteristics of the 44 existing APM systems. Using this database, planners and designers can evaluate specific options appropriate for new projects by comparing similar situations already in operation. This additional information will help in implementing the guidance provided in this document.

CHAPTER 1

Background

Over the past 30 years, air travel has grown dramatically. Planes are larger, and many airports have changed their character and configuration, becoming far bigger and more complex. Some new airport designs include more and larger terminals and facilities that may be spread over large areas. As a result, these airports have become much less walkable due to long distances between facilities and services. Also, the introduction of the A380 aircraft, with over 500 seats, will continue the trend of greater passenger volumes and the resulting larger terminals and longer walks. Airline travel is very time sensitive, and it is critical that all passengers and employees be able to travel efficiently with luggage, strollers, wheelchairs, or other accessories. Recognizing the importance of mobility to passengers and employees, some airports have planned and implemented automated people mover (APM) systems.

APMs are transit systems with fully automated, driverless operations, featuring vehicles that travel on guideways with an exclusive right-of-way. These systems have been developed and implemented in various sizes and configurations since the early 1970s. They have been installed in many different settings worldwide, including airports, leisure facilities, institutions, and urban areas. APM systems are distinct from traditional heavy- and light-rail public transportation in that they operate without drivers or station attendants. Typically, APMs use a narrower right-of-way and smaller vehicles than traditional rail transportation services. The advent of computerized system operations and increased congestion, along with a desire for improved mobility and integration of activity centers, has spurred the development of APM systems.

As of 2010, there are 44 APM systems operating at airports worldwide. Most early APM systems were implemented to facilitate passenger and employee conveyance within the secure area (airside) of an airport—generally conveyance between passenger check-in areas (terminal) and airplane gates (concourse). These APMs allowed greater volumes of passengers to move more quickly over longer distances, connecting large, often dispersed airline terminals. More recently, APM systems have been designed to connect airport terminals with landside facilities such as parking, car rental services, regional transportation services, hotels, and other related employment and activity centers.

While a typical airport's staff is experienced in the planning and implementing of many types of facilities and passenger conveyance systems, they are often less familiar with APM systems and the interface requirements between the APM and the airport facilities served by the APM. This guidebook will help provide such familiarity.

1.1 Research Approach

The approach of this guidebook to planning and implementation of APM systems at airports is to look at APMs from all perspectives—past, present, and future, as well as inward and outward. Specifically, the approach is to look at the historical role of APMs at airports, at present airport applications, and at future technological advances that will allow APMs to meet the needs of tomorrow's airports. At the same time, this guidebook looks inward at the physical components of APMs and outward at the facilities and equipment with which APMs must interface at the airport.

To implement this research approach, specific areas or issues are broken out and presented in a sequenced manner that attempts to parallel the progression from planning and design to implementation and operation of actual APM systems. The specific areas and issues of research are presented as separate chapters, which, in addition to this chapter and the Introduction in Chapter 2, are:

- Chapter 3: History of APM Systems and Their Roles at Airports;
- Chapter 4: APM System Characteristics;

- Chapter 5: Airport APM Planning Process Overview;
- Chapter 6: Needs Identification and Assessment;
- Chapter 7: Matching Needs with Passenger Conveyance Technologies;
- Chapter 8: APM System Definition and Planning Methodology;
- Chapter 9: Project Coordination, Justification, and Feasibility;
- Chapter 10: APM System Procurement;
- Chapter 11: Operations and Maintenance; and
- Chapter 12: System Expansion and Overhaul.

The world of APMs has its own vocabulary and many associated acronyms. To aid the reader of this report, two theoretical APM planning examples are provided in Appendix A. Other appendices include an inventory of airport APM systems (Appendix B), a glossary of APM terms and acronyms (Appendix C), a summary of applicable APM codes and standards (Appendix D), and a passenger flow modeling discussion (Appendix E).

The research team's experience comes from team members who have worked for airport agencies, for APM suppliers, and for APM consultants. An airport peer review was performed on the APM planning methodologies and criteria aspects of the guidebook that are found within Chapter 8. Participants in the peer-review panel were airport staff members. A detailed selection process resulted in staff from six airports populating the peer-review panel. The panel represented a cross section of APM configurations (shuttle versus pinched loop), APM types (airside versus landside), and APM propulsion (self-propelled versus cable-propelled). Panel members reviewed the planning methodology and criteria documents and provided written comments to the consulting team. Comments were then provided to the ACRP 03-06 project panel for review. The resulting comments were then incorporated into the draft guidebook.

CHAPTER 2
Introduction

The 44 airport APMs operating worldwide in 2010 provide greater passenger conveyance capacity over greater distances than ever before. As air traffic continues to grow over time and new airport construction is constrained, the result will be continued passenger growth at existing airports. Undoubtedly, some existing airports will implement their first APM to meet their growing passenger conveyance requirements. Thus the need was identified by ACRP to develop a guidebook that would:

- Assist airports considering the feasibility of an APM, and
- Aid the planning and implementation of APM systems when appropriate.

Additionally, research was needed to provide a historical perspective of airport APM systems worldwide, a review of existing airport APM systems, a discussion of available and evolving APM technologies, and a summary of alternative APM service configurations. Research results were to be presented in a way that provided practical methodologies and planning criteria for conceptual development, evaluation, and implementation of airport APM systems.

2.1 Purpose

The purpose of this guidebook is to assist airport staff and planners/designers in assessing the feasibility of providing an APM system, either airside or landside, at their facility. Furthermore, if an APM system is determined to be feasible, then the guidebook's purpose is to assist airport staff in the planning and implementation of the APM and its interfaces with other airport facilities such as terminal buildings and garages. The guidebook will also assist airport professionals involved with operating airport APMs in terms of operations and maintenance (O&M), APM system expansion, and negotiations for ongoing O&M services.

2.2 Who Should Use This Guidebook?

This guidebook was developed for use by airport planners, architects, designers, and engineers who have responsibility for the technical evaluation of passenger conveyance at an airport. An airport career background is assumed, and therefore certain topics that are airport related, but not APM specific, are covered only at a general level.

2.3 How to Use This Guidebook

How airport professionals should best use the guidebook will vary with the stage or level of the project in which they are involved. History of APM Systems and Their Roles at Airports (Chapter 3), APM System Characteristics (Chapter 4), Needs Identification and Assessment (Chapter 6), and Matching Needs with Passenger Conveyance Technologies (Chapter 7) are valuable to airport planners in the early master planning phase. Airport APM Planning Process Overview (Chapter 5), APM System Definition and Planning Methodology (Chapter 8), and Theoretical Examples of APM Planning and Implementation (Appendix A) are more appropriate for planners and designers where an APM has already been identified as the preferred technology. For APM projects where the APM system design has already been concluded, Project Coordination, Justification, and Feasibility (Chapter 9); APM System Procurement (Chapter 10); and Operations and Maintenance (Chapter 11) are most appropriate. Finally, part of Chapter 11 discusses procurement of ongoing O&M services for an existing APM system. This material and System Expansion and Overhaul (Chapter 12) are included for airport professionals involved with an existing APM system that is operating at their airport.

An important note of caution is warranted for all readers of the guidebook. This document is only a guide, and alone will

not be sufficient to plan and/or implement an airport APM without the participation of professionals with significant APM experience. Part of the reason for this is the sheer magnitude of airport APMs: they require significant airport resources in terms staff effort, and the type of that effort (planning, design, engineering, construction, and testing) varies over the course of a project. Another reason to use this guidebook with caution is that APMs affect other major facilities at the airport. Therefore, if an APM is not implemented properly, it can adversely affect the functioning interface with the other airport facilities.

APMs have their own technical terms and acronyms that can be challenging to those first learning about the technology. A number of these terms are introduced in the next chapter to aid the reader in understanding the general historic trends. More detailed descriptions of APM terms are provided in Chapter 4 (APM System Characteristics) and in the glossary provided in Appendix C.

2.4 Other ACRP Reports

ACRP serves as one of the main ways that the airport industry develops solutions to meet the demands placed on it. ACRP produces a series of research reports, similar to this guidebook, for use by airport operators, local agencies, the FAA, and other interested parties to disseminate findings on important issues facing the industry. Specific ACRP research reports and projects that deal with the topics covered in this guidebook include:

- *ACRP Report 4: Ground Access to Major Airports by Public Transportation,*
- *ACRP Report 10: Innovations for Airport Terminal Facilities;*
- *ACRP Report 25: Airport Passenger Terminal Planning and Design, Volume 1: Guidebook,*
- Project 03-14: "Airport Passenger Conveyance System Usage/Throughput" (in process), and
- Project 03-07: "A Guidebook for Measuring Performance of Automated People Mover Systems at Airports" (in process).

CHAPTER 3

History of APM Systems and Their Roles at Airports

This chapter provides a history of APM systems with an emphasis on airport APMs. The initial airside and landside airport APMs are then described in detail, followed by a more general description of the evolving role of both airside and landside systems over the last four decades.

3.1 History of Airport APM Systems

3.1.1 Origins of Driverless Transport

The first APM in the world was probably built in Salzburg, Austria, at the Festung Hohensalzburg in the 1500s, and is still in use today. Der Reiszug ("the trip") was constructed for the transportation of food to a castle on a hill. The system was 625 ft long on a 67% slope. Early in the 17th century, this system transported building materials used to expand the facility. It is assumed that the original system was driverless; thus, in many ways it is similar to current APM systems. It consists of two cars connected by a cable. It uses onboard water tanks and gravity for propulsion. The tank in the car at the upper station is filled with water until its weight exceeds that of the lower car, then the brakes are released and the cars move and exchange positions.

3.1.2 Beginnings of Modern APMs

Some of the earliest modern-day APM concepts were developed in the 1950s when General Motors investigated driverless vehicles on separate guideways. Later in that same decade, the New York City Transit Authority briefly demonstrated an automated people mover operation along 42nd Street between Times Square and Grand Central Station.

About a decade later, Westinghouse Electric Corporation developed an APM technology called Skybus with federal funding provided by the U.S. Department of Housing and Urban Development. Skybus utilized transistor technology, rubber tires, and center guidebeam guidance. The system was called the South Park Demonstration Project for the Port Authority of

Photo: www.pghbridges.com

PAAC Skybus Demonstration Project

Allegheny County (PAAC). It operated between 1965 and 1966, and while Pittsburgh's urban transportation experiment did not survive, Westinghouse further developed the Skybus technology and implemented a later version at Tampa International Airport 5 years later as the first airport APM.

During the 1970s, U.S. defense contractors diversified into transportation. Boeing supplied APM vehicles for the Morgantown (West Virginia University) automated system in 1975. LTV Aerospace Corporation became an APM supplier

Photo: Lea+Elliott, Inc.

Dallas/Fort Worth Airport AIRTRANS

with an extensive project at the Dallas/Fort Worth Airport (DFW), the 13-mile AIRTRANS system. Although the interest of these aerospace manufacturers in transit technology was short-lived, the systems they built were not; AIRTRANS operated over 30 years at one of the busiest airports in the world while the Morgantown personal rapid transit (PRT) system is still in daily use at the West Virginia University campus.

The U.S. federal government's Downtown People Mover Demonstration Program encouraged cities to build APMs as downtown circulators. Initially, four first-tier cities were selected and received federal funding grants. None of these systems were built. A second round of grants included Miami and Detroit; these systems were built opening in 1985 and 1987, respectively. Although the U.S. government's investment during the 1960s and 1970s in new systems research and development was aimed at urban applications, APMs would go on to achieve greater success at airports throughout the world. Starting with Tampa in 1971 and continuing to the present day, APMs have been instrumental in overcoming the problem of the growing scale of airports in terms of geometry and passenger volumes.

Photo: Lea+Elliott, Inc.

Detroit Downtown People Mover

During the 1970s and early 1980s, much progress was made in other countries, most notably in European countries and Japan and Canada. While these decades saw many new airport and some urban APMs in the United States, development in other countries focused more on urban transit applications.

In 1983 Matra's Véhicule Automatique Léger (vehicle automated light or VAL) system opened in Lille, France, with 8.2 miles of guideway and 18 stations. VAL APMs and many of its associated technological advances, especially automated train control, were subsequently deployed at other urban and airport applications in France. The latest version of the technology was deployed at Paris CDG International Airport in 2007. In the United States, the VAL technology has operated at Chicago O'Hare since the early 1990s.

Photo: www.usa.siemens.com

Matra VAL in Lille, France

In Japan, a strong interest in APMs from government and industrial organizations began to develop in the early 1970s. LTV Aerospace licensed its AIRTRANS technology to Niigata Engineering Company, which made several key improvements. Subsequently, the Japanese government adopted this technology as its standard for self-propelled APMs, and other Japanese suppliers, including Kawasaki and Mitsubishi, entered the APM business. In the ensuing years both urban and airport APMs flourished in Japan. Airport APMs have been installed at the Tokyo–Narita (cable-propelled) and Osaka–Kansai (standard self-propelled) airports; urban APMs have been built in Osaka, Kobe, Tokyo, and Yokohama. Mitsubishi has airport airside APMs operating at Hong Kong and Washington Dulles; has several airside systems under construction at Miami, Dubai, and Singapore Changi airports; and a landside airport system is now operating at Atlanta International Airport. Niigata has built a system at the Taipei International Airport.

APM development in Japan has been distinctly different from that in North America and Europe in terms of their standardization. In Japan, one supplier can build on another's system, whereas APM systems developed elsewhere are proprietary and very different from one another and are not interchangeable.

In Canada, the Urban Transportation Development Corporation (UTDC) developed a new automated streetcar/light rail transit (LRT) vehicle technology for Toronto following an extensive study of automated guideway systems. The resulting Automated Light Rail Transit (ALRT) is characterized by automated operations, steel wheel (steel rail suspension and guidance), and linear induction motors. After the first application in Toronto, UTDC went on to implement the ALRT technology for the Detroit (urban) People Mover and the Vancouver Sky Train. UTDC was later acquired by other Canadian companies: first SNC/Lavalin and then Bombardier. Bombardier

Photo: www.bombardier.com

New York–JFK AirTrain

expanded the vehicle size (ALRT II) and added a new line and fleet in Vancouver and is constructing the urban Putra Line in Kuala Lumpur, Malaysia. The ALRT II technology was also implemented at New York–JFK International Airport in an extensive landside system called AirTrain.

3.1.3 Drivers of the Driverless

The emergence and growth of APMs at airports since the early 1970s can be attributed to three major factors, or drivers: (1) the increase in airport passenger volumes and the resulting expansion of airport terminal facilities, (2) shortcomings of existing transport technologies to meet advancing airport conveyance requirements, and (3) improvements in APM-related technologies, particularly solid-state command-and-control components.

The first driver, airport passenger volumes, increased substantially in the United States during the late 1970s and 1980s. The advent of the U.S. Airline Deregulation Act of 1978 was a big reason for this increase. Competition among the U.S. airlines took the form of lower ticket prices and greater numbers of flights. While domestic enplanements had increased an average of just 4.1% annually from 1970 to 1975, this jumped to 6.4% annually in the succeeding 15-year period. Enplanements rose from 170 million in 1970 to 466 million in 1990. New so-called "discount" airlines emerged in the early 1980s and helped fuel this increase. Airlines began transitioning their operations from point-to-point service to hub-and-spoke service with one or two airports serving as an airline's hub and multiple spokes serving feeder airports. Passengers traveling between two spoke airports would depart the origin spoke airport, land at a hub airport, then transfer to another flight bound for the destination spoke airport. Airline hubbing operations increased passenger conveyance needs significantly at the hub airports. In addition, the growth of passenger volumes overwhelmed the older terminal facilities at some airports, necessitating the addition of other terminal buildings and satellites for which the APM was well-suited to act as an efficient connector. Some airports/new airport terminals built in the 1970s, like Tampa, Orlando, and Dallas/Fort Worth, used APM technology as an integral part of their configuration for airside and landside connections.

The second driver of APM growth was the inadequacy of existing transport technologies. The technologies most often used for transporting people in high-volume environments did not meet this emerging airport need. Moving walks, standard rail transit, and bus transit technologies had all evolved to meet certain conveyance needs, but not the specific needs of airports. This new airport conveyance requirement was for high passenger volumes (with baggage) over the now longer but still relatively short distances (1,000 to 5,000 ft). Specifically, other technologies failed to meet the emerging airport conveyance needs because:

- Moving walks could not accommodate the high volumes generated by multiple aircraft arrivals and could not meet the trip time or walk distance thresholds for longer distances.
- Standard light or heavy rail required longer headways, larger tunnel diameters or elevated track structures, longer board/alight times, open platforms exposing passengers and baggage to the trough below (power rail), could not take advantage of their higher speeds due to short station spacing, and had less train capacity flexibility.
- Transit buses required a vertical level change to the apron level, multiple steps in boarding and alighting the vehicle, and often exposed passengers to the elements during boarding and alighting. Bus routes were more circuitous and safety concerns arose with buses crossing active aircraft taxilanes.

The third driver behind the emergence of APM technology was the advent of improved APM technologies, particularly the transistor and solid-state technology. Integrated circuits allowed the complex control equipment required for the safe and reliable operation of a smaller vehicle (typically 30- to 40-foot long) to be compact and lightweight enough to easily fit on the vehicle. The necessary control and vital safety equipment could now be built into modules to be used for propulsion, braking, and door controls, as well as monitoring the performance of these subsystems. Microprocessors and software-based train control have continued to evolve and expand the capabilities of APMs and other forms of fixed guideway transit.

3.1.4 The First Airport Airside and Landside APMs

The first airport airside APM at Tampa and the first landside APM at Dallas/Fort Worth are worthy of special discussion. The factors behind the decisions to implement revolutionary new passenger transport systems illuminate the general airport planning process that is described in detail in Chapter 5. Both systems are described in greater detail in Appendix B along with the other airport APM systems in operation today.

Tampa International Airport

In the early 1960s the Hillsborough County Aviation Authority identified the need to expand capacity at Tampa International Airport while maintaining a high level of service (LOS) to airline passengers. The key level-of-service criterion in their decision-making process was to limit passenger walk distances between the roadway curb and aircraft gate to 700 ft. Adding aircraft gates by extending the existing terminal did not meet these criteria; thus the decision was made to implement a new facility with a unique satellite concourse design.

The new design had a central processing facility surrounded on all sides by satellite concourses housing the aircraft gates, as shown in the Tampa International Airport photo. Economies of scale were present at both the processing facility and the satellite concourses. The single processing facility was optimized to accommodate the ticketing, bag check, and bag claim activities. The satellite concourses had gates along the exterior of the concourse that allowed a higher ratio of aircraft gates to building area than was previously achievable.

Parking garages were located adjacent to the central processing facility, allowing easy access for passengers but requiring the satellite concourse to be located further from the processing facility. The APM shuttles thereby became an integral element of the new airport concept by allowing easy passenger access between the processing facility and aircraft gates.

Photo: www.bombardier.com

C-100 Vehicle at Tampa International Airport

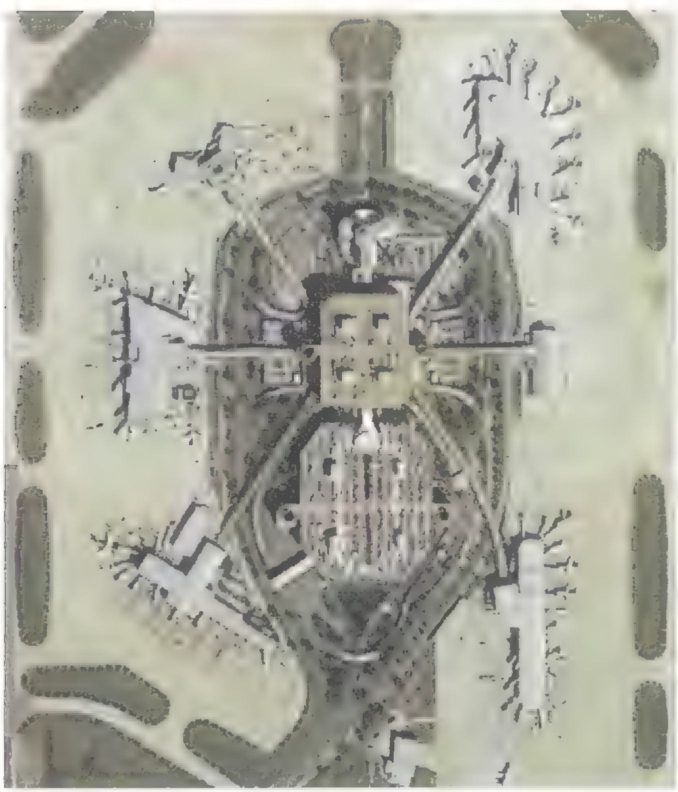


Photo: Hillsborough County Aviation

Tampa International Airport

Without the APM, the walk distance criteria would have been greatly exceeded; this made the APM a must-ride system. In this way, the APM shuttles allowed the walk distance criteria to be achieved. Each satellite concourse was served by two APM trains, each with its own guideway. Each lane operated independently from the other so that a failure on one guideway would not impact the other lane.

To ease the APM alight/board process, the shuttle stations, located at the same level as aircraft gates, were designed with three platforms to separate counter-directional flows. When the train arrived at a station, the alighting passengers would depart the APM to an empty side platform. After a short delay, the opposite side doors would open to the center platform where boarding passengers had accumulated (and could board a train on either lane). The flow-through design has proved to be very efficient in passenger processing (reducing station dwell times) and has been subsequently used at many APM shuttles.

The first phase of the Tampa Airport had four airside concourses, each with its own dual-lane shuttle with two single-car trains. Lengths of these shuttles ranged from 800 to 1,000 ft. APM headways, or time between successive train departures, were about 1.5 minutes for each of the four original shuttles. Since that time, two more concourses have been added, the cars have been increased from one to two per train, and the original satellites have been expanded to accommodate additional aircraft gates.

Dallas/Fort Worth International Airport

In 1970, the Dallas/Fort Worth Airport was under construction and a people mover was one of the requirements. After funding development work by two start-up companies, Varo

Photo: DFW International Airport

DFW Airport Terminals

and Dashaveyor, the airport board asked these two firms to partner with larger companies for financial purposes. Varo partnered with LTV Aerospace Corporation, and Dashaveyor partnered with Bendix, and later Westinghouse Airbrake Company (WABCO).

A unique aspect of the original Airport Transportation System (AIRTRANS) was the plan to transport both people (passengers and employees) and cargo (baggage, mail, supplies, and trash). No prototype or operating hardware of this complexity was in existence at the time, and a creative effort with models and simulations was required to convince the airport board that the system could be built.

A request for proposal for AIRTRANS was issued in May of 1971; two proposals were received from LTV Aerospace and WABCO. After evaluation, LTV was declared the winner and notice-to-proceed (NTP) was given on August 2, 1971. The system was constructed in a remarkably short time of 30 months using fast-track construction methods. All aspects of the original service concept were built and successfully demonstrated. At one time, passenger, employee, baggage, mail, supply, and trash services were operated, although the cargo services were ultimately terminated.

AIRTRANS began service in January of 1974. It was the largest people mover system of any kind in the world in terms of length, fleet size, and scope. The alignment was a series of interconnected loops serving a total of 17 passenger stations with three inter-terminal routes and two remote parking routes. The alignment was partially elevated and partially at-grade with single or two-car trains following different operational routes that served the different airport terminals and parking facilities. The original system included a fleet of 51 passenger vehicles and 17 cargo vehicles.

In the early 1990s, American Airlines implemented its TrAAm system, which used completely refurbished/modernized AIRTRANS equipment and operated within the original system's alignment. The resulting system helped the airline to cut in half the connection times between distant aircraft gates.

A new elevated Skylink system replaced TrAAm in 2005 to serve the airside connection needs of the airport. The new system is one of the largest airport systems in the world and provides a capacity of 5,000 passengers per hour per direction (pphpd). From the start at DFW, APMs have provided a wide

Photo: Lea+Elliott, Inc.

AIRTRANS and Skylink at DFW

range of conveyance service and allowed an origin/destination terminal design to transform itself into one of the largest airline hub airports in the world.

3.1.5 The Airside Shuttle Era: 1970s–1980s

The original airport APM system was the airside shuttle system at Tampa in 1971. For the next 20 years, the vast majority of airport APM implementations were airside two-lane shuttles with a single train operating separately on each of the two lanes. These systems were relatively short in length (1,000 to 2,000 ft), served two stations, and had relatively simple propulsion and train control. One landside single-lane shuttle system was constructed at Bradley International Airport in Hartford in 1974, but the system never opened for revenue service because of funding considerations.

Photo: www.bombardier.com

Airport Airside Shuttle APM

The airside shuttle APM systems were typically elevated above the apron (e.g., Tampa, Miami, and Orlando). Two early exceptions to this were the systems at Seattle and Atlanta. The Seattle APM is installed in a tunnel and consists of two independent multi-train loops connected by an independent single-lane shuttle. The Atlanta system opened in 1980 as an airside APM with two parallel guideway lanes that are pinched at both ends, allowing trains to switch over to the opposite lane for the return trip. This feature allows more than two trains to operate simultaneously (see Section 4.2). However, simple shuttles were the dominant guideway configuration of the first two decades of APM applications, with a single U.S. manufacturer, Westinghouse and its C-100 technology, as the dominant supplier.

3.1.6 Pinched Loops Come of Age: 1990s

Longer APM systems serving multiple terminals and stations with pinched-loop operations became the common theme for APM implementations in the 1990s. Airside and landside APM implementation at major hubbing airports occurred at Chicago O'Hare, Frankfurt, Denver, Hong Kong, and Newark, all between 1993 and 1996. Like the pinched-loop system in Atlanta, the systems utilized switches at each end of a dual-lane guideway, allowing APM trains to switch to the opposite lane for the return trip. Multiple trains with service frequency as low as 2 minutes allowed for high-capacity transport of passengers over distances from 5,000 to 10,000 ft. A wider range of APM suppliers began to provide these longer systems. Greater station spacing led to an emphasis on higher speeds than with the earlier shuttle applications.

New airport shuttle systems were implemented during the 1990s as well. While earlier shuttles tended to be self-propelled (motors on vehicles), a number of shuttles were now cable-propelled using wayside motors; examples include Cincinnati and Tokyo (Narita). Airport implementations were no longer predominately in the United States, as new systems were opened in England, Germany, Hong Kong, and Japan.

3.1.7 APMs in the Mainstream: 2000 and Beyond

As airport APMs entered the 21st century, growth and innovation continued on all fronts: guideway configurations, system length, train speed, number of suppliers, vehicle suspension, vehicle propulsion, and the number of implementation countries. Some of the industry innovations included:

- Top-suspension of the H-Bahn Dusseldorf APM,
- Detachable-grip cable in Minneapolis allowing pinched-loop operations.
- Landside system at New York's JFK and an extension of the Newark AirTrain, which both go off airport property to connect with regional rail transit systems.
- "Spanning" runways in Zurich (under) and Mexico City (around),
- Technology replacement in Birmingham (maglev to cable-propelled),
- Train control and vehicle upgrades while maintaining operations in Seattle and Atlanta,
- Communications-based train control,
- New system and subsystem suppliers,
- Pilot demonstration of a small vehicle PRT system at London Heathrow, and
- In the first decade of the 21st century, the number of airport APMs has almost doubled; APMs are recognized as a vital component to major airports.

3.1.8 APM Industry Overview

The convergence in the 1960s of the technology and system engineering advances of the space program and the willing-

ness to publicly fund new transportation systems research and development gave rise to early APMs. The technology found its niche in meeting the growing conveyance needs of rapidly expanding airports in the United States, and later in Europe and Japan, during the 1970s and 1980s. Since that time, APMs have become technically mature, and many APM innovations have been applied to other modes. No doubt the future will see further growth and maturation of the APM industry. A summary of all airport APMs currently operating is provided in Table 3.1-1. Additional descriptions of these systems are contained in Appendix B of the guidebook.

3.2 The Roles of APMs at Airports

The role of APMs is different for the airside and landside uses. On the airside (or secure side) of an airport, an APM typically connects aircraft gates with airport processing functions (ticketing, bag claims, etc.) or with other aircraft gates. On the

Table 3.1-1. Summary of existing airport APMs.

Airport	Airside or Landside	Started Service
1. Tampa	Airside	1971
2. Seattle	Airside	1973
3. Atlanta	Airside	1980
4. Miami	Airside	1980
5. Houston	Landside	1981
6. Orlando	Airside	1981
7. Las Vegas	Airside	1985
8. London Gatwick	Landside	1987
9. Singapore Changi	Airside and Landside	1990
10. Tampa	Landside	1990
11. London Stansted	Airside	1991
12. Paris–Orly	Landside	1991
13. Pittsburgh	Airside	1992
14. Tokyo Narita	Airside	1992
15. Chicago	Landside	1993
16. Cincinnati	Airside	1994
17. Frankfurt	Airside	1994
18. Osaka Kansai	Airside	1994
19. Denver	Airside	1995
20. Newark	Landside	1996
21. Hong Kong	Airside	1998
22. Kuala Lumpur	Airside	1998
23. Houston	Airside	1999
24. Rome	Airside	1999
25. Minneapolis/St. Paul	Landside	2001
26. Detroit	Airside	2002
27. Dusseldorf	Landside	2002
28. Minneapolis/St. Paul	Airside	2002
29. Birmingham (UK)	Landside	2003
30. New York–JFK	Landside	2003
31. San Francisco	Landside	2003
32. Taipei	Airside	2003
33. Zurich	Airside	2003
34. Dallas/Fort Worth	Airside	2005
35. Madrid	Airside	2006
36. Toronto	Landside	2006
37. Mexico City	Airside	2007
38. Paris–CDG	Airside	2007
39. Paris–CDG	Landside	2007
40. London Heathrow	Airside	2008
41. Beijing	Airside	2008
42. Seoul Incheon	Airside	2008
43. Atlanta	Landside	2009
44. Washington Dulles	Airside	2010

Source: Lea+Elliott, Inc.

landside (or non-secure side), an APM typically connects the airport processing functions with other landside facilities such as parking, car rental, or regional transit.

3.2.1 Airside APM Systems

APM systems that operate on the secure side of the airport are called airside APM systems. These systems transport passengers between gates or between terminals and gates. The passengers who ride these systems have cleared security or have deplaned from arriving aircraft.

Airside systems are also used to transport arriving international passengers between their gates and the customs and immigration facilities. These systems can have a special requirement to maintain separation between arriving international passengers who have not yet cleared customs and all other airline passengers and airport employees. Airside APM systems are usually designed to accommodate passengers with only carry-on bags, as these passengers would not be carrying large checked baggage beyond security or off an international flight.

Two different functions of airside APM systems are described below.

Terminal-to-gate or origin/destination (O/D) connections—APM systems connect main terminal buildings (processing areas) to aircraft gates in the same or a separate (e.g., satellite concourse) building. All origin passengers are processed in the same terminal building and ride the APM to their departure concourse. Similarly, arriving destination passengers ride the APM to the terminal building to reclaim baggage and/or transfer to a domestic flight or leave the airport.

Gate-to-gate or transfer connections—APM systems are used to serve as a connection between aircraft gates within one or more concourses in order to facilitate the movement of transfer passengers or passengers returning to a different terminal from that of their departure fight. The APM system provides a fast connection between gates, which can thus be located further apart than with other conveyance technologies such as moving walks or apron buses.

Photo: Lea+Elliott, Inc.

Narita: Terminal-to-Satellite Concourse

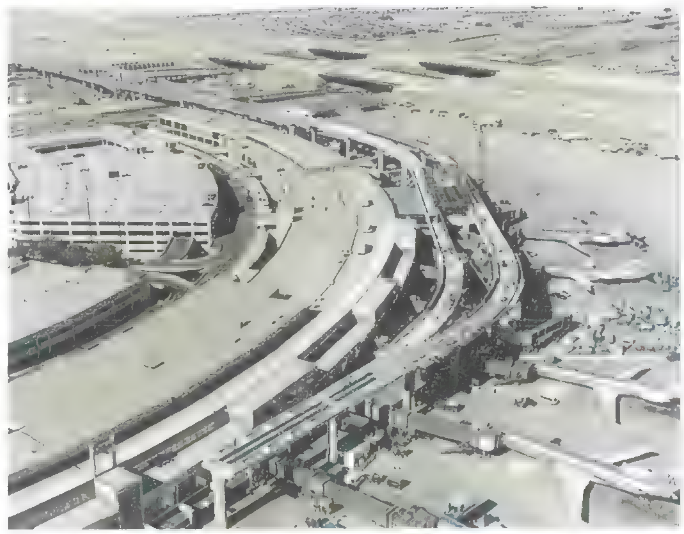


Photo: Lea+Elliott, Inc.

DFW: Gate to Gate/Terminal to Terminal

3.2.2 Summary of Airside APM Roles

A tabular summary of existing airside APM system characteristics is provided in Table 3.2-1. The new functional and geometric capabilities that APMs have brought to the airside of the airport have provided new opportunities, including:

- Allowing remote concourses to be located further from the main terminal processing functions by providing faster passenger connection times and reducing walk distances,
- Enabling more gates in individual remote concourses through greater inter-facility transport capacity and faster gate-to-gate connection times,
- Allowing major airlines to achieve hubbing (transfer) operations of over 60 gates and over 20 million annual passengers (MAP), and
- Enabling concourse/gate expansion on the opposite side of a runway(s) without having to also add roadways, parking, and terminal processing facilities to that side of the airport.

Table 3.2-1. Airport airside APMs.

Airport	Year Opened	Alignment Configuration	APM Function[1]	Length (miles)[2]
Tampa	1971	Shuttles	O/D	0.7[3]
Seattle	1973	Shuttle & Loops	O/D	1.7[3]
Miami	1980	Shuttle	O/D	0.4
Atlanta	1980	Pinched Loop	Transfer	1.0
Orlando	1981	Shuttles	O/D	1.5[3]
Las Vegas	1985, 1998	Shuttles	O/D	0.2, 0.6
Singapore	1990, 2006	Shuttles	Transfer	0.7[3]
London (Stan)	1991	Pinched Loop	O/D	0.4
Tokyo	1992	Shuttles	Transfer	0.2
Pittsburgh	1992	Shuttle	Transfer	0.4
Cincinnati	1994	Shuttle	Transfer	0.2
Frankfurt	1994	Pinched Loop	Transfer	1.0
Osaka Kansai	1994	Shuttle	Transfer	0.7
Denver	1995	Pinched Loop	Transfer	1.2
Kuala Lumpur	1998	Shuttle	O/D	0.8
Hong Kong	1998	Pinched Loop	Transfer	0.8
Houston	1999	Pinched Loop	Transfer	0.7
Rome	1999	Shuttle	O/D	0.4
Detroit	2002	Shuttle	Transfer	0.7
Zurich	2003	Shuttle	O/D	0.7
Taipei	2003	Shuttle	O/D	0.8
Minn/St. Paul	2002	Shuttle	Transfer	0.5
Dallas/Fort Worth	1974, 2005	Loops	Transfer	4.9
Madrid	2006	Pinched Loop	Transfer	1.7
Paris–CDG	2007	Shuttle	O/D	0.4
Mexico City	2007	Shuttle	O/D	1.9
London LHR	2008	Shuttle	O/D	0.4
Beijing	2008	Pinched Loop	O/D	1.2
Seoul	2008	Shuttle	O/D	0.6
Washington Dulles	2010	Pinched Loop	Transfer	1.9

Source: Lea+Elliott, Inc.
[1]The predominant APM conveyance function origin/destination and/or transfer that the APM serves.
[2]Length is measured in dual-lane miles of guideway.
[3]Combined length of multiple shuttles.

3.2.3 Landside APM Systems

APM systems that operate on the non-secure side of the airport are called landside APM systems. These systems transport passengers between multiple processing terminals or between processing terminals and other landside activity centers at the airport. The passengers who ride these systems have not cleared security prior to boarding the trains. Landside APM systems are usually designed to accommodate passengers with large checked baggage or even baggage carts. Therefore, the same APM vehicle that might carry 70–75 passengers on the airside would carry only 40–50 on the landside. Trip times on these systems may be long to reach remote parking lots, rental car sites, or off-airport intermodal facilities. Two general functions of landside APM systems are described below.

Landside circulation—APM systems enable the movement of passengers between airport activity centers such as terminals, parking lots, and rental car centers. These APM systems reduce the number of buses operating on the airport roadway, thereby lessening roadway congestion and auto emissions on airport property.

Transit connections—APM systems also serve to connect an airport terminal with an urban or regional transit system. Passengers can connect to transit systems such as city buses or regional rail systems through intermodal centers. These APM systems also help to reduce roadway congestion and auto emissions in the region.

Landside Circulation

Landside airport APM systems, similar to airside systems, have allowed airports to expand their physical size and passenger throughput while still meeting level-of-service thresholds for connect time and walk distance.

APM systems currently operate at airports with peak hour passenger flows of 1,000 pphpd or more and alignment lengths from 1,000 ft to 3 miles. For APM systems connecting a main terminal with (1) other terminals, (2) rental car center, (3) long-term parking, and (4) urban/regional transit, system demands are in the range of 2,500 to 4,500 pphpd. APM systems serving all such applications tend to be longer: from 2 to 3 miles. Systems serving fewer than the four applications listed above often have proportionately lower demands and are typically shorter in length. Systems serving only car rental or long-term

parking may have hourly demands from 1,000 to 2,500 pphpd and range from 1,500 ft to 2 miles.

For remote facilities located more than 3 miles from the main terminal, buses are the more typical transport technology. Longer landside APM systems (length of guideway) typically serve multiple landside terminals, each having its own ticketing and bag claim functions. The APM's main function is to interconnect the terminals. Connecting a terminal with international service to one or more domestic terminals also occurs at a number of landside applications, including Chicago O'Hare, New York–JFK, Newark, San Francisco and Paris (CDG and Orly).

Terminal roadways can quickly become the landside bottleneck, resulting in long delays for buses and autos. Lengthening or widening terminal roadways eventually becomes physically impossible, if not cost prohibitive. At airports such as Newark, Chicago O'Hare, Düsseldorf, and Birmingham, landside APMs provide an efficient means of supplementing the terminal roadways in providing access to and from the terminal buildings. These landside APMs allow the airport to increase O/D passenger volumes without having to increase roadway capacity.

Photo: San Francisco International Airport

Landside APM under Construction

Landside Transit Connections

Many major airports have a regional rail station located within the terminal complex, allowing an easy connection between rail stations and ticketing/bag-claim functions. However, other airport terminal functions may not be served well by a single rail station location, and regional rail technology's geometric constraints (curves and grades) and bypassing lines or operational constraints do not easily allow multiple rail station locations within an airport. The cost and constructability impacts of regional rail station location(s) have led some airports to locate a regional rail station remote from the terminal complex.

With more distant regional rail stations from the terminal, APMs and buses provide the connection to the terminal. Passenger arrival patterns at the station via the regional rail service depend on that service's train frequency and train size. Typically, long trains arrive periodically and unload a large group of passengers in a very short time period. Such surged demand is well suited to the high capacity provided by APMs with shorter and more frequent trains.

Many airports have an existing or planned regional rail station between 200 and 1,000 ft from the terminals. These are almost exclusively served by walkways. APMs serve a small number of airport rail stations with distances ranging from 1,000 ft to 2 miles between the station and the terminal. Buses serve a larger number of airport rail stations, with the distance between the station and the terminals ranging from one-half mile to 3 miles for most of these systems. The maximum distance served by frequent, express bus service is approximately 12 miles.

Major international airports have a wide variety of land uses on their premises. With airport growth, the expansion of terminals and roadways often forces other facilities such as rental car centers and parking structures to relocate to more remote locations. Landside APMs have been used to facilitate such relocations at many airports.

Commercial Developments

Commercial development opportunities on airport or adjacent lands are a revenue-generating land use that is under consideration for planned landside systems at a number of major airports. The ability of a landside APM to connect the airport facilities and a regional rail station with a commercial development property can enhance that property's value and provide additional revenues to the airport.

Summary of Landside APM Roles

A tabular summary of existing landside APMs and their characteristics is shown in Table 3.2-2. In summary, the landside roles that APMs have played include:

- Reducing airport roadway congestion and emissions by eliminating airport bus traffic and thus allowing an airport to increase its O/D MAP for a given roadway system,
- Better connecting separate processing terminals (and their respective aircraft gates) to allow hubbing operations between facilities,
- Helping to consolidate rental car facilities by better accommodating their high-volume demands, and
- Providing a nearly seamless connection to airport facilities from regional transit, helping promote transit modal access to the airport, and reducing regional auto congestion and emissions.

Table 3.2-2. Airport landside APMs.

Airport	Year Opened	Alignment Configuration	Service To	Length (miles)[1]
Houston	1981	Loop	Terminals	1.0[2]
London Gatwick	1987	Shuttle	Terminals, Intermodal	0.7
Tampa	1990	Pinched Loop	Parking, Car Rental	0.6
Paris–Orly	1991	Pinched Loop	Terminals, Intermodal	4.5
Chicago	1993	Pinched Loop	Terminals, Parking, Intermodal	2.7
Newark	1996	Pinched Loop	Terminals, Parking, Intermodal, Car Rental	3.2
Minneapolis/St. Paul	2001	Shuttle	Parking, Intermodal, Car Rental	0.2
Dusseldorf	2002	Pinched Loop	Parking, Intermodal	1.6
New York–JFK	2003	Pinched Loop	Terminals, Parking, Intermodal, Car Rental	8.1
Birmingham (UK)	2003	Shuttle	Intermodal	0.4
San Francisco	2003	Loops	Parking, Intermodal, Car Rental	2.8
Singapore Changi	1990/2006	Shuttles	Terminals	0.8
Toronto	2006	Shuttle	Terminals, Parking	0.9
Paris–CDG	2007	Pinched Loop	Terminals, Parking, Intermodal	2.1
Atlanta	2009	Pinched Loop	Terminal, Car Rental, and Convention Center	1.4

Source: Lea+Elliott, Inc.
[1]Length is measured in dual-lane miles of guideway.
[2]Single-lane loop system converted to dual-lane mile equivalent.

CHAPTER 4

APM System Characteristics

In this chapter the basic APM system is described from a component or subsystem level and from a system-configuration level. The APM components are then described in more detail in terms of the current state of the art and potential improvements for the different components.

4.1 APM Systems and Their Components

APM systems are fully automated and driverless transit systems that operate on fixed guideways in exclusive rights of way. APMs can include technologies that are also called automated guideway transit (AGT) and, when fully automated, monorails and low-speed magnetic levitation (maglev) systems. The main differences between APM systems and other transit technologies are that APMs are driverless and that the vehicles are not subject to roadway-based congestion and interference. While APMs are most commonly found at airports, there are an increasing number of urban APMs and some metro systems that are fully or partially automated.

An APM system is a combination of interrelated subsystems and components designed to operate as a cohesive entity that provides safe, reliable, and efficient passenger transport. APM systems are proprietary in nature and are typically not interchangeable. This means that a system must be procured in its entirety from one supplier rather than implemented from a blend of several suppliers' products. Thus APM system equipment is typically procured using a design-build (DB) or design-build-operate-maintain (DBOM) approach. At airports, the APM facilities are usually procured as separate design-bid-build (DBB) projects, although sometimes a partial or full system-facility DB or DBOM approach is used. This is discussed further in Chapter 10.

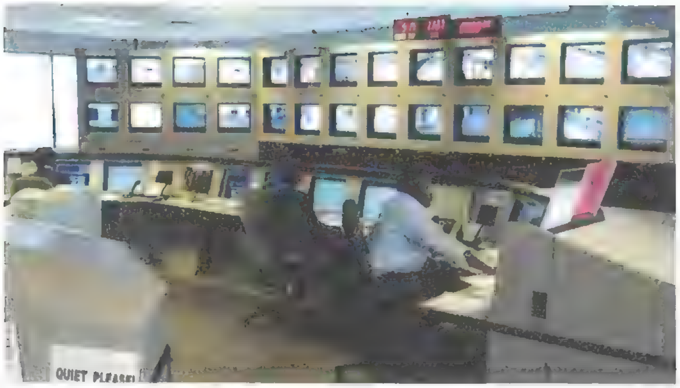
An APM system consists of the operating system and fixed facilities. The operating system consists of the proprietary subsystem equipment essential to the APM system operation. Facilities are the buildings, rooms, and guideway that house or physically support the operating system equipment. There are six main components to an APM system, each with its own system and facility aspects:

1. Vehicles;
2. Guideway;
3. Propulsion and system power;
4. Command, control, and communications;
5. Stations; and
6. Maintenance and storage facility.

Vehicles—APM vehicles are fully automated, driverless, either self-propelled or cable-propelled, reliable, and provide a high degree of passenger comfort and safety. Vehicle speed, capacity, and maximum train length are dependent on the type of technology selected and the system configuration. Typical 40-ft-long APM vehicles generally carry between 50 and 75 passengers, depending on passenger types and their baggage characteristics.

Guideway—The guideway of the APM system refers to the track or other running surface (including supporting structure) that supports, contains, and physically guides APM vehicles designed to travel exclusively on it. The guideway structure itself is part of the system facilities that may be provided by the APM supplier. The guideway can be constructed at ground level (at grade), elevated (above grade), or below grade in a tunnel.

Propulsion and system power—Electric power is required to propel vehicles and energize system equipment. APM vehicles are electrically powered by either direct current (DC) or alternating current (AC) provided by a power distribution subsystem. Vehicle propulsion may be provided by DC rotary motors, AC rotary motors, or AC linear induction motors (LIM), or via attached cables. Self-propelled APM vehicles are electrically powered by onboard motors using either 750 or 1500 volt DC or 480 or 600 volt AC, distributed along the guideway by a way-



Source: Lea+Elliott, Inc.

APM Central Control Facility

side, rail-based power distribution subsystem. Cable-propelled vehicles are pulled by an attached cable that is driven from a fixed electrical motor drive unit located along the guideway, usually at one end of the system. Cable-propelled vehicle housekeeping power (lights, electronics, HVAC, etc.) is usually provided by a 480 volt AC wayside power rail subsystem.

Command, control, and communications—All APM systems include command, control, and communications equipment needed to operate the driverless vehicles.

Stations—Stations are located along the guideway to allow passenger access to the APM system. The station equipment typically includes automatic station platform edge doors and dynamic passenger information signs. The stations also have APM equipment rooms to house command, control, and communications equipment and other APM equipment.

Maintenance and storage facility—The maintenance and storage facility (MSF) provides a location for all vehicle maintenance and storage, as well as administrative offices. Items housed in the MSF include maintenance equipment, tools, machinery, recovery vehicle, equipment for train control and power within the MSF, and any other equipment/systems associated with maintaining (and possibly storing) the APM vehicles.

Functions performed within the MSF include maintenance of vehicles and other subsystem equipment, vehicle cleaning/washing, and storage of parts, tools, and spare equipment.

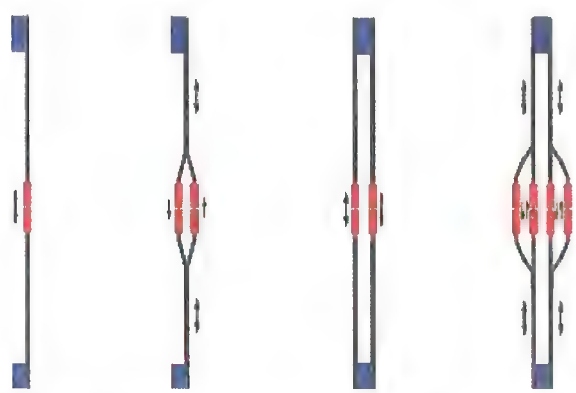
4.2 APM System Configurations

This section describes overall APM system characteristics, including APM system guideway alignment and APM platform configurations. There are also several distinctive physical and operational characteristics of APM systems that define a system's alignment configuration. The physical characteristics are used to determine the best configuration to suit a particular application in an airport environment. The different system alignment configurations include:

- Single-lane shuttle,
- Single-lane shuttle with bypass,
- Dual-lane shuttle,
- Dual-lane shuttle with bypass,
- Single Loop,
- Double loop, and
- Pinched loop.

4.2.1 Shuttle System Configurations

Shuttle systems are the most basic APM configuration. Figure 4.2-1 illustrates four basic types of two-station APM shuttle system configurations.



Source: Lea+Elliott, Inc.

Figure 4.2-1. Shuttle systems.

Single-Lane Shuttle

A single train shuttles back and forth between two endpoints on a single guideway. Two stations are most common, but additional stations can be accommodated. This simple shuttle is best suited to transporting passengers between two points in a low-demand environment. Because a single point failure along the guideway will shut down the single-lane shuttle, this configuration should only be used where passengers have the alternative of walking or where a standby means of conveyance is available.

Single-Lane Shuttle with Bypass

Two synchronized trains pass each other in the bypass area of the guideway. Because each train can be independently propelled, there is the potential for a degree of redundancy and failure management capability. A third station can be added in the bypass area. Single lane shuttles with bypass are limited to two trains. This configuration is slightly more complex operationally than the single-lane shuttle because the trains must be synchronized to avoid delays at the bypass. This configuration has a role in relatively low-demand situations to transport passengers between two points.

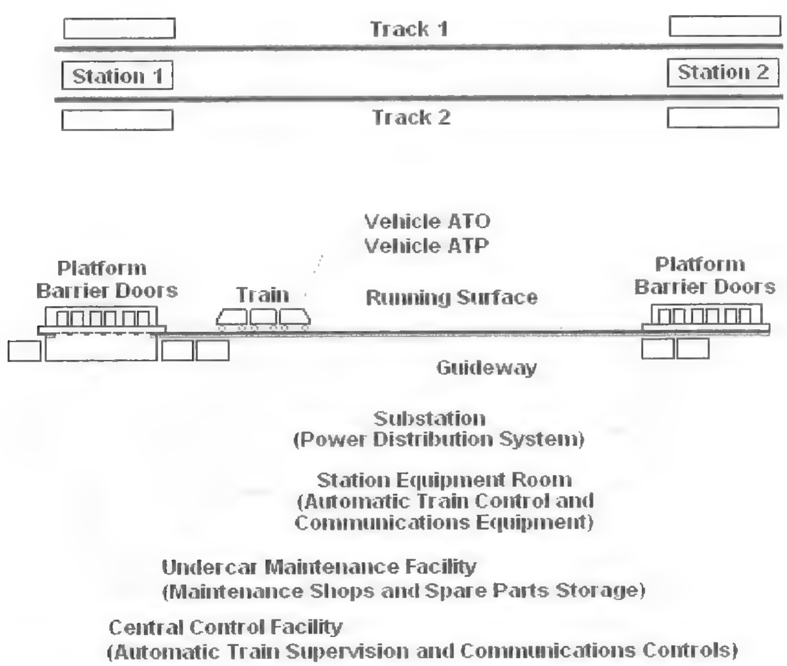
Dual-Lane Shuttle

Two trains shuttle back and forth independently in a synchronized manner on separate guideways. During non-peak times this configuration can be operated as a single-lane shuttle to allow for maintenance on the other lane/train, or in an on-call mode, like elevators. Two stations are most common, but additional stations can be accommodated. Dual-lane shuttles provide both vehicle and wayside redundancy for good failure management and are limited to two trains. This configuration serves higher demand levels than the single-lane shuttles for passengers traveling between two points. To provide APM system configurations in the context of the different APM components, Figure 4.2-2 shows the plan view of a two-station, self-propelled APM shuttle above a profile view of the same shuttle configuration.

A cable-propelled APM shuttle is similar in configuration to a self-propelled shuttle, but there are differences with a number of the APM components, as shown in Figure 4.2-3. Propulsion is a clear difference between cable- and self-propelled systems. Propulsion is provided at the station (bullwheel) for a cable system, while it is provided in the vehicle (onboard motor) for a self-propelled system.

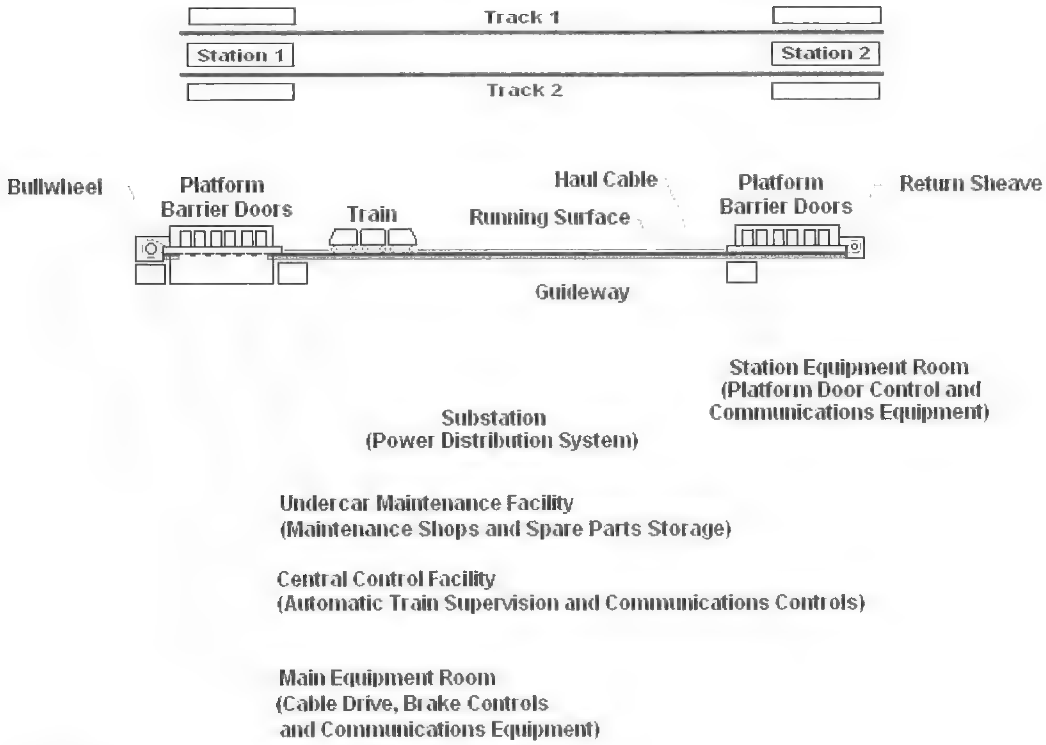
Dual-Lane Shuttle with Bypasses

Two synchronized trains pass each other on each lane in the bypass area of the guideway. This configuration doubles the capacity potential of the dual-lane shuttle configuration by allowing a maximum of four trains without requiring four full guideway lanes. This configuration is suitable for higher demand levels than the other shuttle configuration for transporting passengers between two points.



Source: Lea+Elliott, Inc.

Figure 4.2-2. Typical APM self-propelled shuttle.



Source: Lea+Elliott, Inc.

Figure 4.2-3. Typical APM cable-propelled shuttle.

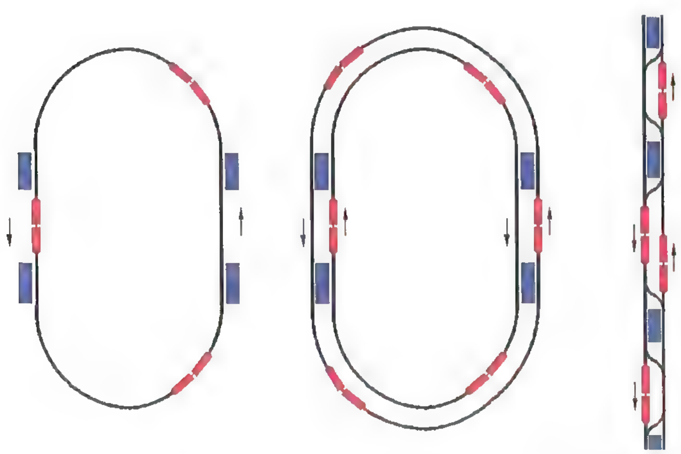
4.2.2 Loop System Configurations

Loop and pinched-loop system configurations differ from shuttle configurations and are described below. Figure 4.2-4 illustrates the range of loop-type APM system configurations.

Single Loop/Double Loop

Loop configurations allow multiple stations to be served with a self-propelled (but typically not cable-propelled) vehicle fleet. Distances and number of trains are not limited. As the scale of a single-loop system increases, the one-way movement of its trains becomes problematic. For example, in a multistation loop, if the passenger's destination is the adjacent station in the opposite direction of the one-way train movement, the passenger must ride through the entire system and all other stations to reach the destination. Failures on a single loop can cause a shutdown of the entire system unless there are pre-planned backup shuttle routes between unaffected stations. The single loop should only be used for nonessential services that can provide an alternative means of conveyance in the event of failures. Even then it has serious operational drawbacks.

The double-loop configuration solves these problems by offering trains traveling in both directions. Passengers can be instructed as to the shortest route to their destination station. Double loops provide redundancy to lessen the impact of failures. Double-loop configurations are suitable for nonlinear applications that serve multiple stations and have higher demand levels than can be served by single-loop or shuttle systems.



Source: Lea+Elliott, Inc.

Figure 4.2-4. Loop systems.

Pinched Loop

Although having the visual appearance of a dual-lane shuttle, the trains in a pinched-loop configuration travel in a loop by reversing direction and changing lanes via switches at the

end stations. Intermediate switches between selected stations are often provided for failure management purposes, allowing trains to be temporarily rerouted around a problem area that would otherwise disrupt service. Stations along the alignment are served in both directions of travel. Distances and number of trains are typically not limited. This configuration is well suited to linear, must-ride applications requiring high-capacity frequent service, multiple stations, multiple trains, and high reliability.

Advances in cable-grip subsystems (detachable grips) now allow cable-propelled technologies to be used in limited pinched-loop configurations with multiple cables/cable drives, typically serving two or three stations and with cable transfer done at stations. There are two such cable-grip APM systems currently in operation at airports.

Figure 4.2-5 shows the pinched-loop configuration within the context of the different APM system components. It is important to note that the pinched-loop system includes switch machines for crossovers and yard access, as well as an expanded central control equipment room, which typically includes train control functions for the yard access and departure testing.

4.3 State-of-the-Art APM Components

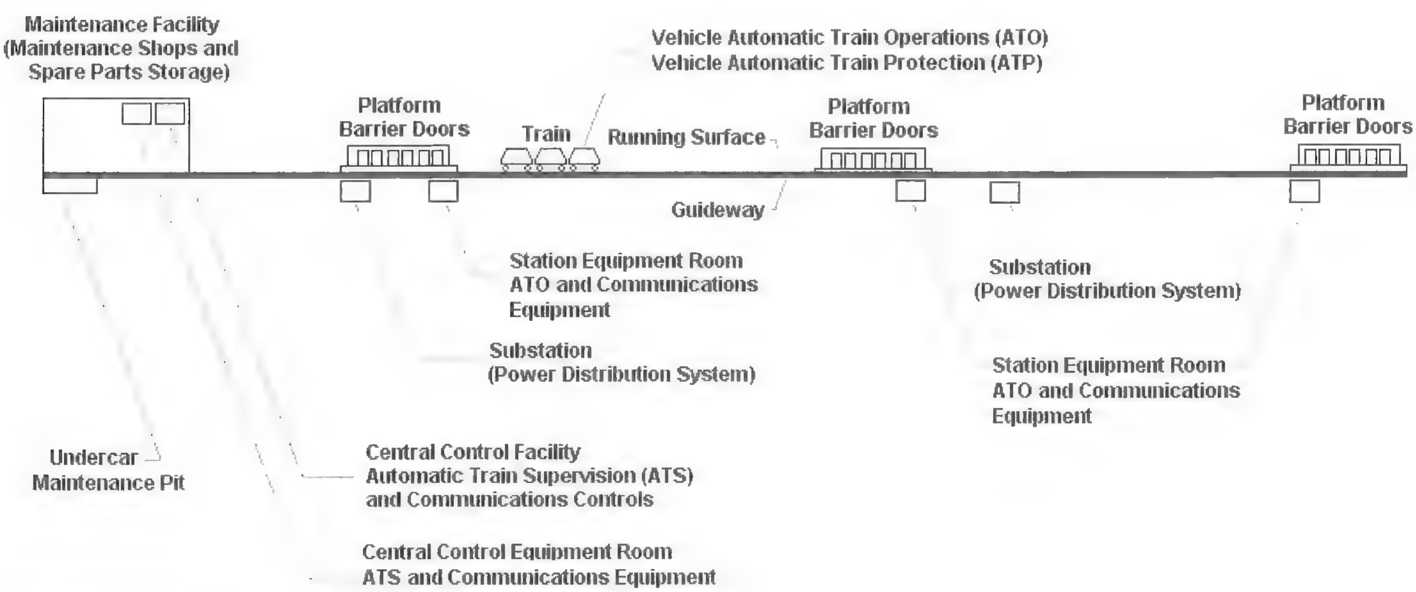
This section discusses APMs at the component or subsystem level. It focuses on the current state of APM systems that are now operating at airports. There continue to be significant advances in many subsystems and components, particularly those associated with command/control and power distribution, so that aspects of the current state of the art may be quickly superseded.

An APM system is a combination of interrelated, interacting subsystems and elements designed to operate together as a cohesive system. The primary elements of an APM consist of the operating system and fixed facilities. The operating system consists of proprietary subsystems and is typically provided as a complete system by a single APM supplier. This is not necessarily the case in Japan, where the standard Japanese APM can have subsystems provided by several entities. Facilities are the buildings, rooms, and guideway that house or physically support the operating system equipment, and may be provided by the APM system supplier, depending on the project's procurement strategy. Figure 4.3-1 illustrates the organization of APM system components. Each is discussed in detail in the subsequent sections.

4.3.1 Vehicles

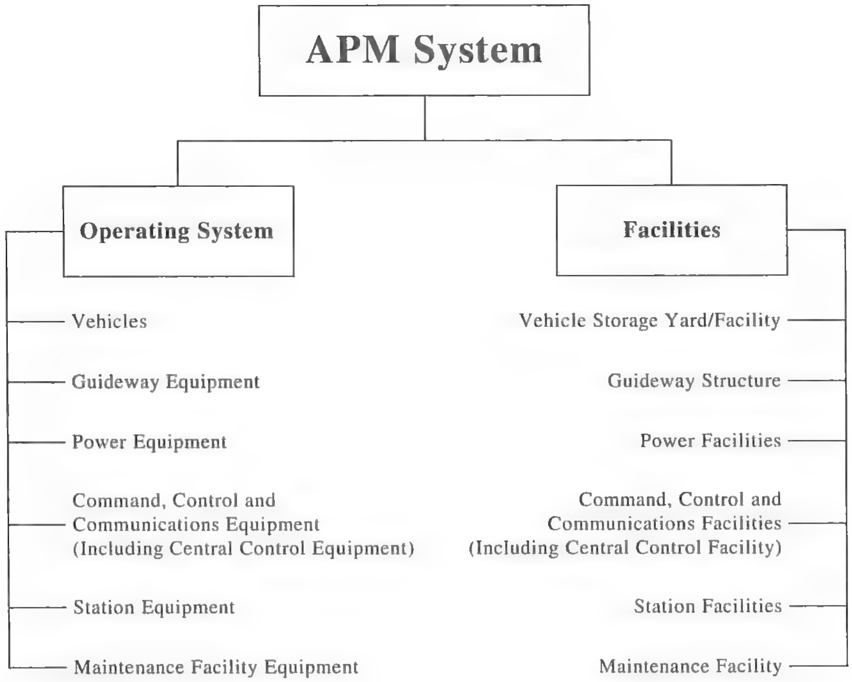
APM vehicles are fully automated, either self-propelled or cable-propelled, and provide a high level of passenger comfort and safety. Vehicle speed, capacity, and maximum train length are dependent on the type of technology selected. The majority of APM vehicles have capacities of 50–75 passengers at airports, depending on their baggage characteristics. Landside systems have the lower end of the capacity range (passengers having all their bags), while airside systems have the upper end of the range (passengers having carry-on bags only).

Self-propelled vehicles are powered by either DC or by AC. Vehicle propulsion is provided by DC rotary motors, AC rotary motors, or AC LIM. With LIM, the motor's stator is



Source: Lea+Elliott, Inc.

Figure 4.2-5. Typical APM pinched-loop system.



Source: Lea+Elliott, Inc.

Figure 4.3-1. Organization of APM system components.

typically installed on the vehicle and the rotor is installed on the guideway. Cable-propelled vehicles are attached to a cable and are pulled along the alignment. Most cable systems have the vehicles permanently attached to the cable, while more recent systems are detachable, which allows multiple trains to operate in pinched-loop operations.

The typical airport APM single vehicle is approximately 40-ft long and 10-ft wide and can be coupled into trains as long as four to six vehicles. APM vehicles are typically equipped with a ventilation and air conditioning system, automatically controlled doors, a public address system, passenger intercom, a pre-programmed audio and video message display, fire detection and suppression equipment, seats, and passenger handholds. Some APM vehicles are designed to accommodate baggage carts.

APM vehicles can be supported by rubber tires, steel wheels, air levitation, or magnetic levitation. A detailed description of each type of APM vehicle suspension follows:

Rubber tires—APMs using a rubber-tire suspension bogie also use concrete or steel guidance structures. The running surfaces are attached to a primary surface (concrete or steel) in a manner that maintains proper alignment. When climate conditions require, heating may be provided on sections of the guideway exposed to the elements to aid in maintaining good tire adhesion.

Steel wheels—Some APM vehicle types use steel-wheel bogie suspension. The primary advantages of steel wheels on rail tracks are simplified vehicle guidance, low rolling resistance, and faster switching. Rail tracks are typically directly

Photo: www.bombardier.com

Two-Car APM Shuttle

Photo: www.bombardier.com

Steel-Wheel APM Train

fixed to concrete cross ties. Steel-wheel technologies can achieve higher operating speeds.

Air levitated—Air-levitated APM vehicles ride on a cushion of air, allowing them to travel without friction on the running surface. The vehicle and the concrete guideway "flying" surface are separated by an air gap. Low-pressure air flows from blowers in the vehicle chassis to air pads. Special surface finishing requirements are needed to provide a smooth surface texture since any unusual roughness can contribute to rapid wearing of the pads.

Magnetic levitation—Maglev vehicles are magnetically levitated and propelled by linear motors. Electromagnetic maglev systems use permanent magnets or electromagnets and have a relatively small gap between the car and the running surface. There are high-speed (200+ mph) and low-speed (30–60 mph) maglev systems, but only low-speed maglev is applicable to airport APMs. The initial Birmingham (UK) Airport landside APM was a maglev system.

The APM vehicle steering and guidance mechanisms vary by technology. Steering inputs are provided to vehicle bogies through lateral guidance wheels that travel in continuous contact with guideway-mounted guide rails. The steering inputs cause the bogies, usually located at both ends of each vehicle, to rotate so that vehicle tires do not "scrub" as they go through alignment curves. Side and center guidance mechanisms are used by different manufacturers, and each type has unique characteristics.

Side guidance is generally provided by steel or concrete elements located along the sides of each guideway lane. The side guidebeams/rails may be located outside the main wheel paths and can be located either above or below the top of the primary running surface. Side guidance generally requires special mechanisms and trackwork to maintain positive guidance through track switches.

Center guidance systems generally use a structural steel guidebeam along the guideway centerline to provide guidance and steering inputs. Guide wheel configurations and materials generally roll along both sides of the center guidebeam, trapping the beam between the guide wheels. Center guidebeams are located at various elevations relative to the top of primary running surfaces. Special movable replacement-beam type switches are usually employed at track switch areas. These types of switches replace a straight guidebeam with a curved turnout guidebeam.

Photo: Lea+Elliott, Inc.

Side Guidance

4.3.2 Guideway

The guideway of the APM system refers to the track or other running surface (including supporting structure) that supports and physically guides vehicles that are specially designed to travel exclusively on it. The guideway structure may be provided by the APM supplier, as discussed in Chapter 10 (APM System Procurement).

Photo: www.Doppelmayr.com

Guideway Running Surface

The guideway can be constructed at grade, above grade, or below grade in tunnels. Depending on the selected supplier and other considerations, the guideway may be constructed of steel or reinforced concrete. For elevated guideways, the size of the structure (columns) varies with span length, train loads, and any applicable seismic requirements. Spans typically range from 50 ft to 120 ft in length.

The APM supplier provides guideway equipment that generally includes running surfaces, guidance and/or running rails, power distribution rails, signal rails or antennas, communications rails or antennas, and switches. For technologies that

employ linear induction motors for propulsion, guideway equipment may also include either reaction rail (called the rotor) or the powered element of the motor, called the stator.

An emergency walkway along the guideway is sometimes required to provide emergency egress from a disabled train. It is typically continuous, preferably at vehicle floor height, and provides an unobstructed exit path to a station or other place of refuge or escape. The adjacent photo shows the emergency walkway between two guideway lanes for an elevated airside shuttle at Las Vegas McCarran Airport. Some APM systems allow for emergency egress along the guideway itself with passengers evacuating from the front or rear of the train.

Photo: Lea+Elliott, Inc.

Emergency Walkway

Crossovers provide the means for trains to move between guideway lanes. They are required for pinched-loop operations and are desirable for failure management purposes on such system configurations. Crossover requirements vary significantly among APM system suppliers and each supplier's switch and crossover requirements are discrete in that their geometric and other requirements are largely inflexible. Many guideway configurations have guideway switches that allow trains to switch between parallel guideway lanes or between different routes on a system. Different APM technologies have different types of switches, including:

- Rail-like,
- Side,
- Beam replacement, and
- Rotary.

Because of the guidance systems of most rubber-tired APMs, a crossover is generally composed of two switches (one on each guideway lane) connected by a short length of special trackwork. Steel wheel/rail APMs use rail switches, and the Siemens VAL systems use a slot-follower switch that is similar to a traditional rail crossover switch.

4.3.3 Propulsion and System Power

Electric power is required to propel vehicles (propulsion/traction power) and energize system equipment. Propulsion and system power are typically configured such that power will be supplied by substations spaced along the guideway. The substations house transformers, rectifiers (if required), and the primary and secondary switchgear power-conditioning equipment. Power distribution can be provided either as three-phase AC or DC. The distance between substations for AC systems is limited to about 2,000 ft, whereas for DC systems the distance is typically limited to one mile.

Vehicles are either self-propelled or cable-propelled. A more detailed description of both types of propulsion follows:

Self-propelled—These APMs may use electric traction motors or LIM. Self-propelled APMs are electrically powered by onboard AC or DC motors using (typically) either 750- or 1,300-volt DC or 480- or 600-volt AC wayside rail-based power distribution subsystems. Self-propelled APMs are not limited in guideway length. These technologies can be used for shuttle, loop, pinched loop, and network guideway configurations.

Cable-propelled—These APMs use a steel cable or "rope" to pull vehicles along the guideway. The cable is driven from a fixed electrical drive motor located along the guideway. Prior to the advent of the detachable grip, cable-propelled systems had typically been limited to use for shorter shuttle systems up to 4,000 ft. Onboard equipment power is usually provided by a 480-volt AC wayside power.

There has been recent interest among airport owners/operators in reducing power requirements for APM systems. Heightened cost awareness, the variable price of energy, and a focus on sustainability have created a strong interest in lowering power requirements. At the time of this guidebook's publication, a comparative analysis of regenerative braking energy-capture technologies was being performed at a number of airports with operating APM systems. These analyses were taking into account the physical space requirements of the equipment, the space availability along the APM system to accommodate such equipment, and the cost/benefit ratio of various equipment (technology) alternatives. While analyses findings were not available at the time of the guidebook publication, energy savings is expected to be an important issue for APMs in the future.

4.3.4 Command, Control, and Communications

All APM systems include command, control, and communications equipment to operate the driverless vehicles. Each

APM system supplier, based on its unique requirements, provides different components to house the automatic train control (ATC) equipment. ATC functions are accomplished by automatic train protection (ATP), automatic train operation (ATO), and automatic train supervision (ATS) equipment.

ATP equipment functions to ensure absolute enforcement of safety criteria and constraints. ATO equipment performs basic operating functions within the safety constraints imposed by the ATP. ATS equipment provides for automatic system supervision by central control computers and permits manual interventions/overrides by central control operators using control interfaces.

The APM system includes a communications network monitored and supervised by the central control facility (CCF). This network typically includes station public address systems, operation and management (O&M) radio systems, emergency telephones, and closed-circuit televisions. The bases for many of these communication requirements are emergency egress codes such as NFPA 130. The CCF is the focal point of the control system and can vary in size from a simple room with one or two operator positions and a minimal number of computer and CCTV monitor screens (simple APM shuttle) to a large room with multiple operator and supervisor positions and a large array of screens and other information devices (complex pinched-loop APMs).

4.3.5 Stations

Stations are located along the guideway to provide passenger access to the APM system. Stations for airport APMs are typically online, with all trains stopping at all stations. The station equipment provided by the APM system supplier typically includes automatic station platform edge doors and dynamic passenger information signs. The stations typically have station APM equipment rooms to house command, control, and communications equipment and other APM equipment.

Photo: Lea+Elliott, Inc.

Center Platform of a Dual-Lane Shuttle

Photo: Lea+Elliott, Inc.

APM Vehicle Dwelling at Station

The station platforms and vertical circulation are sized to accommodate the system ridership and station flow estimates. Since it is difficult and costly to expand APM station platforms once constructed, it is usually recommended that stations initially be designed and constructed to meet the estimated ultimate airport APM ridership demand.

Dimensions defining the minimum width of the APM platforms and stations are developed based on analyses that take into account the train lengths of the ultimate design vehicle, reasonable allowance for passenger circulation and queuing at the platform doors and escalators, passenger queuing and circulation requirements based on ridership flow assumptions, and reasonable spatial proportions and other good design practices.

In addition to the APM train doors, the station has doors that align with a stopped/berthed train and the two-door systems operate in tandem. The automatic station platform doors are integrated into a platform edge wall and provide a barrier between the passengers and the trains operating on the guideway.

The station platform doors provide protection and insulation from the guideway noise, heat, and exposed power sources in the guideway. The interface between the station platform and the APM guideway is defined by the platform edge wall and automated station doors. This wall and door system is designed to allow evacuation of the APM vehicles in the event of a misalignment of the vehicle with the station doors. This requirement is accommodated by either a castellated wall configuration or a straight wall with opening panels.

All airport APMs have station platform walls and doors for safety reasons as well as climate control. Some urban APMs do not have such walls and doors, as riders are familiar with the danger at platform edges and do not tend to have baggage/strollers that could exacerbate potential safety problems.

Dynamic passenger information signs are typically installed above the platform doors and/or suspended from the ceiling at the center of the station to assist passengers using the system. These dynamic signs provide information regarding train destinations, door status, and other operational information.

The barrier wall, doors sets, and passenger circulation/queuing area within the APM station and adjacent to the APM berthing position are commonly referred to as the platform. A single station can have multiple platforms. The type of platforms used depends on the type of APM configuration, physical space constraints, and any passenger separation requirements. An examination of the roles each platform type serves is needed to determine the best configuration to suit a particular application in an airport environment.

Based on station size along with ridership and circulation parameters, the platform configuration can take two basic forms. The first is flow through, where the station has a center platform for boarding passengers located between the two APM guideway lanes that are in turn flanked by two exterior or side platforms for alighting passengers. This configuration can reduce dwell times by having the doors on the alighting (side) platform open first and then several seconds later having the doors on the boarding platform open. This separates conflicting passenger flows and allows the arriving passengers to begin to clear the vehicle before departing passengers begin to board the vehicle. The second configuration is cross flow, where there is a single center platform or two side platforms where boarding and alighting occurs through the same set of APM train doors. In this instance, passengers are encouraged to allow the arriving passengers to alight before boarding takes place.

Center Platforms with Cross-Flow Movements

A center platform configuration mixes both boarding and alighting passengers in cross-flow movements. Center platforms may be used in the bypass area of a single-lane shuttle with bypass alignment configuration, and may also be used with dual-lane shuttles, pinched loops, double loops, and some network APM configurations. Center platforms typically require vertical circulation to move passengers up and over (or down and under) the guideways. Vertical circulation is not required at the end-of-line station configurations of the shuttle or pinched loop if passengers can circulate beyond the ends of the guideways.

Side Platforms with Cross-Flow Movements

A single-side platform is a single loaded platform that requires mixing of boarding and alighting passengers, again in cross-flow movement. A potential advantage of a single-side platform (depending on the associated architecture) is the ability to be on the same level as the facility that it serves and not require vertical circulation to go up and over the guideway. However, a single-side platform provides a relatively low level of service and can increase dwell time at stations because board/deboard times will be high. By providing two side platforms, the level of service for the station can be greatly increased, and board/deboard times reduced. However, providing two side platforms is more costly and demands more physical space, which may outweigh the benefits of better passenger service. Two side platforms, one on either side of a single guideway, can provide simultaneous flow-through boarding and alighting. Side platforms (single or double) are the only platform type that can be used with a single-shuttle APM configuration.

Triple Platforms with Flow-Through Movements

A triple-platform configuration is a combination of both side and center platforms. Sometimes referred to as flow-through platforms, triple platforms allow for simultaneous boarding and alighting. For example, boarding passengers move into the APM vehicle from the center platform while alighting passengers depart the vehicle and move onto the side platforms. Other uses are also possible such as segregating passenger types (for instance secure and non-secure passengers) on a single train. Consideration needs to be made for the cost and physical space needs of triple platforms and the requirement for potentially three independent sets of vertical circulation elements. Although triple-platform configurations are the most demanding in terms of cost and space requirements, they provide the highest level of service to passengers.

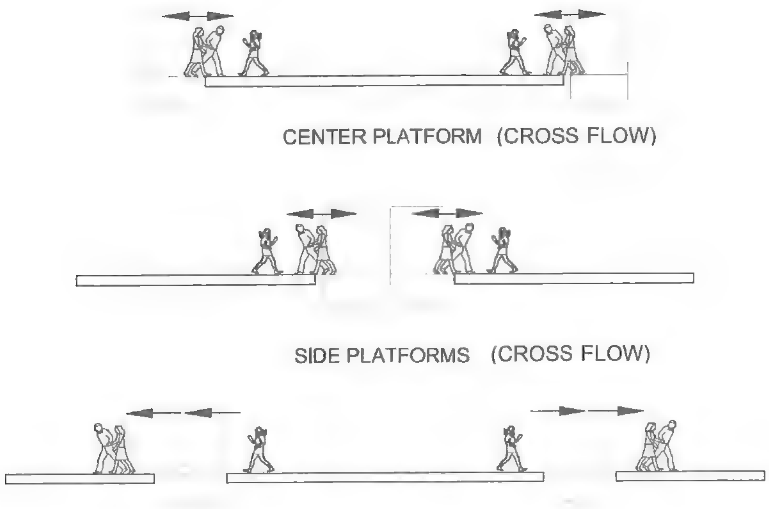
The three types of APM platform configurations are provided in profile view in Figure 4.3-2 below.

4.3.6 Maintenance and Storage Facility

The maintenance and storage facility provides a location for vehicle maintenance and storage as well as administrative offices and central control. The maintenance functions include vehicle maintenance, cleaning, and washing; shipping, receiving, and storage of parts, tools, and spare equipment; fabrication of parts; and storage of spare vehicles.

For larger APM systems (non-shuttles), the MSF is typically a facility located independent from the operating alignment. When in this configuration, vehicle testing and test track functions can generally be performed on the guideway approaching the MSF.

Meanwhile, simple shuttle systems often have the MSF located under one of the system stations. An example of maintenance below a shuttle station is provided in the photo of the Las Vegas McCarran airport airside APM shuttle system.



Source: Lea+Elliott, Inc.

Figure 4.3-2. Platform configurations.

Source: Lea+Elliott, Inc.

MSF Located Below Station

4.4 Prospective APM Components

A number of APM system and component concepts have emerged since APMs first began operating at airports in 1971. Some concepts never advanced beyond the conceptual phase, while others were developed into prototype systems. The prototype systems were, in some cases, implemented and became industry standards, while others were discontinued. The successful systems currently available for airport APM systems have been discussed in the prior section of the guidebook.

This section focuses on prospective APM systems and their components. *Prospective systems* are defined as those that have not yet been implemented at airports but might have potential for future implementation.

A new concept for an APM system, component, or subsystem faces considerable technical, schedule, and financial obstacles in transitioning from concept to a service-proven product. These obstacles are met in steps, including:

1. Developing the concept through stages of engineering, and refining the design to make it meet performance and budget (weight, size, cost, etc.) requirements,
2. Developing a prototype of the system or component,
3. Testing the prototype thoroughly (for operation, performance, safety, and other aspects) on a test track/facility (which could be computer simulation for train control systems),
4. Refining the design/prototype based on the testing program and then testing it further,
5. Formalizing the design and packaging of the product, and
6. Promoting the new product to prospective customers.

This process can take years, particularly for a completely new product. Some suppliers have attempted to bring new products to the market without undertaking all of these steps, often with negative consequences: either no one buys it or there are additional research, development, and re-engineering efforts required during product production, resulting in considerable cost and schedule impacts.

Few airports are willing to accept a new system or major new subsystem without it being fully service proven. Airports are typically not in the research and development business, and they prefer a system that will meet all performance requirements from the first day of operation. Several airports have, in the past, taken on new systems. Currently one airport owner/operator, British Airports Authority, is a partner in the development of a new APM technology (PRT) for use at London Heathrow. Most airport managements, however, do not want

to be the first to implement a new product, and it usually takes a considerable effort to convince them to accept an APM that has not already been proven through previous implementation(s) or extensive testing.

This section discusses some of the prospective APM systems and/or subsystems that are currently emerging and vying to become future industry standards.

4.4.1 Vehicles

Small vehicles, holding just two to four passengers, are a prospective APM system component not currently in operation at any airport or urban application. Such small vehicles could be part of a PRT system that would have different system characteristics from current APM systems (see also Section 4.4.7).

PRT is not a new concept. The *Lea Transit Compendium* (Volume II, No. 4) provided detailed information on ten separate PRT supplier technologies in 1975, none of which developed into industry standards.

Photo: British Airports Authority

BAA Demonstration PRT Project

The British Airport Authority (BAA) is currently implementing a pilot demonstration project to evaluate a landside PRT system at London Heathrow. The system will connect Terminal 5 with a remote parking area and includes 2.6 miles of guideway and 18 vehicles. The demonstration system is scheduled to open for passenger service in late 2009. The full-scale project could consist of a 20-mile guideway network with 50 stations and approximately 300 vehicles. BAA selected and became partners with Advanced Transport Systems Ltd. for the project, which will utilize the ULTra vehicle concept (shown in BAA Demonstration PRT Project photo). Some of the external benefits of this project identified by BAA include increased land values and office space rentals, congestion relief, and accident reduction.

PRT vehicle capacity for this landside implementation will be between two and three passengers (as compared with a maximum of four passengers for an airside application). Depending on their baggage characteristics, this capacity limitation could pose challenges for larger groups traveling together, requiring them to divide into multiple groups.

Distinct from PRT, a prospective APM vehicle subsystem currently being developed is active steering. In this concept, the vehicle utilizes an alignment database, a travel database, and a vehicle positioning actuator to correlate the two databases. The actuator actively steers by cross-referencing the real-time vehicle position with desired/future position (travel database). The vehicle also has a simple failsafe mechanical guidance system to be used in the event of failure of the active steering system. The ULTra PRT system is proposed to use this guidance approach. Mitsubishi is also undertaking prototype testing for this prospective vehicle guidance system on its Crystal Mover APM technology. Incorporation of active steering concepts into commercial APM systems will require rigorous safety analyses and certifications to ensure passenger safety.

Other technological advances are also finding their way onto APM vehicles. Onboard CCTV systems are now commonplace, and airports are increasingly requiring that cell phone service, wireless internet access, and other amenities be provided on APM vehicles. APM suppliers are continually advancing their offerings to meet these needs and provide a competitive advantage for their technology.

4.4.2 Guideway

The active steering concept described above has APM guideway implications. The concept would not need side or center guidance rails (or power rails, as described in section 4.4.3), which would simplify the guideway equipment and possibly structure. Without the guidance and power equipment on the guideway, the running surface could potentially serve as the egress walkway (replacing the need for a separate walkway system). This would reduce the facility (guideway) capital cost, while the reduced equipment requirements would reduce the system capital cost.

4.4.3 Propulsion and System Power

Significant advancements in battery technologies and other types of energy storage and distribution are expected to find their way into APM systems. APM suppliers are developing systems that more effectively manage the way APM systems consume electrical energy. Some are developing energy management algorithms and subsystems that more effectively manage train movements and propulsion power consumption,

such as regenerative breaking that uses the energy required to slow one train to drive or accelerate others. Some APM suppliers are developing onboard battery technologies that promise to eliminate power distribution and power rails along the guideway.

Magnetic levitation, combined with linear induction motor propulsion systems, have begun to compete with more conventional rubber-tired, onboard rotary traction motor APMs. Results in the UK and United States have been mixed, but technological advancements in Japan have brought this technology to fruition. The promise of no moving parts in vehicle propulsion systems and resulting reductions in maintenance costs makes these technologies very attractive to airport operators. Good ride quality, low noise, strong performance, and the ability to operate in all weather conditions are also touted as advantages of these technologies.

4.4.4 Command, Control, and Communications

As the procurement of APM systems is primarily based on the DBOM approach, the vehicle suppliers usually provide their own ATC system technology or have long-term relationships with a specific ATC system supplier. Historically, APM systems have used fixed-block ATC systems—first relay-based, and more recently, microprocessor-based. Beginning in the 1980s, a new type of control system called communications-based train control (CBTC) was developed, which uses a moving block approach to achieve considerably closer vehicle headways. CBTC systems are now widely used and are largely supplanting fixed-block technology in APM applications.

It seems likely that prospective APM systems will rely even more heavily on CBTC train control systems, except perhaps in certain long-distance applications, where fixed block technology may offer cost savings. Advancement in CBTC technology will likely further shorten the headways between successive trains. While this is a very desirable goal, there are design limits currently imposed on ATC systems (no physical contact of vehicles or trains, online stations, and the undesirability of stopping trains on the guideway to wait for a train stopped in the station ahead) that, unless modified, will limit the practical time-separation of following trains.

4.4.5 Stations

Offline stations, located on guideways parallel to the mainline guideway, are a prospective APM system improvement. These were used on the initial Airtrans system at the DFW Airport but have not been used on airport APMs since. They are also used on the Morgantown urban APM that, although it has larger vehicles, operates like a PRT system. They are part of the PRT system concept but could also be part of a conventional APM system.

Photo: British Airports Authority

Rendition of Future PRT Station at London Heathrow

Station length is a critical planning and design issue for off-line stations. For example, a PRT station would typically accommodate multiple vehicle berths (docking locations); the exact number will depend on the forecasted passenger demand for that station. However, for the current PRT concepts, each station configuration has a maximum berth number beyond which the station throughput begins to decline. For locations where demand requires more than the optimal number of berthing locations, it is recommended that two or more offline stations be constructed.

4.4.6 Maintenance Facility

New maintenance procedures and equipment are typically developed by manufacturers concurrently with development of new subsystem equipment. Consequently, such prospective maintenance aspects are subsystem-specific and not a characteristic of APM systems in general. A major goal of all manufacturers (and APM system owners) is to minimize maintenance in every form as a means of achieving lower system operating costs.

4.4.7 APM System Characteristics

Route Networks

A prospective APM system characteristic is a network alignment configuration in contrast to the linear nature of currently operating airport APMs. The network alignment configuration allows specific trains to serve specific routes (combinations of stations). Overlapping routes allow different levels of capacity to be provided over different parts of the network. This could allow the system to match capacity with demand better than linear alignments, which typically provide a constant capacity over the entire system.

An example of a route network system (with routes illustrated) is shown in Figure 4.4-1. This example reflects the operations of the AIRTRANS system at Dallas/Fort Worth International Airport prior to its decommissioning in 2005.

Offline stations are often assumed with a network alignment and allow trains to bypass stations that are not assigned to that particular route.

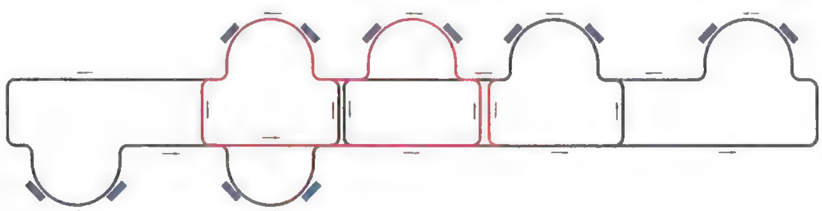
PRT Networks

A PRT network operation is a prospective APM operational characteristic. PRT networks contemplate nonstop service between the origin station and the destination station; this is different from route networks where each train stops at each station along the route. Individual vehicles are available (waiting empty) at offline stations, thus minimizing wait times by passengers.

Proper positioning of PRT vehicles at stations requires empty vehicles to be routed through the network as part of an empty-vehicle management system. The combination of empty-vehicle management, empty-vehicle waiting at stations, and in-use vehicle load factors of 50% (average party size of two passengers) will likely result in higher levels of unused system capacity even during peak demand periods. An example of a hypothetical PRT network is shown in Figure 4.4-2.

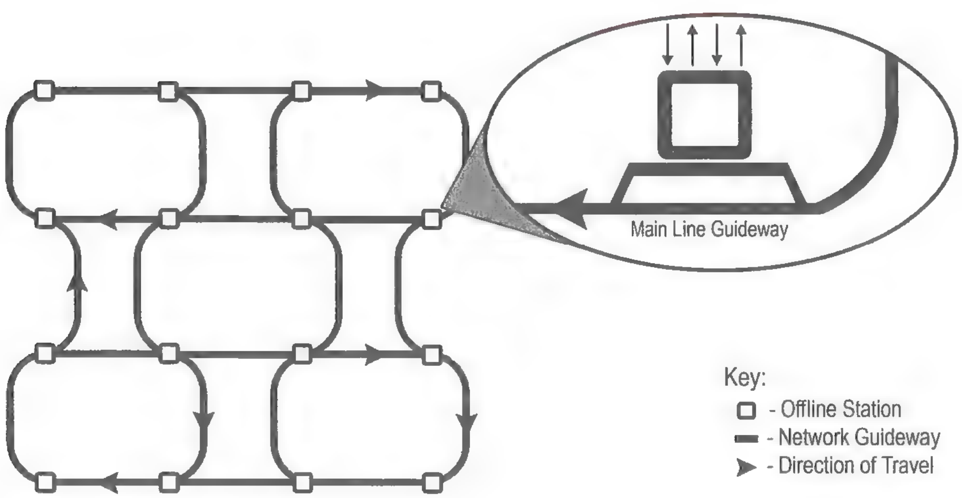
4.4.8 Summary of Prospective Components/Characteristics

No predictions are made in this section as to which prospective APM component or system characteristic will successfully transition into operational, service-proven status. Of the components and characteristics listed above, many already have transitioned and some seem well on their way, while others are coming back in a several-decade cycle. Advances in the APM industry are often incremental. Components in the APM field have sometimes migrated to the standard urban rail technologies of light rail and rapid (heavy) rail. This is especially true in the train control (signal) subsystem. Technological advances in APM components and subsystems have been continuous since their introduction to airports in 1971, and such advances are expected to continue in the future.



Source: Lea+Elliott, Inc.

Figure 4.4-1. Route network system.



Source: Lea+Elliott, Inc.

Figure 4.4-2. Hypothetical PRT network.

CHAPTER 5

Airport APM Planning Process Overview

This chapter provides an overview of the typical planning process for APMs at airports. Each component of the APM planning process is described in greater detail in Chapter 8 (APM System Definition and Planning Methodology), Chapter 9 (Project Coordination, Justification, and Feasibility), and Appendix A (Theoretical Examples of APM Planning and Implementation). The objective of this chapter is to take the APM system components described in Chapter 4 and place them into the overall planning context.

5.1 General Airport APM Planning Process

The planning process for an APM project involves a carefully documented program, starting with the simple articulation of airport needs and ending with a complete project definition that is ready for preliminary design and engineering. Throughout the planning process, it is important to maintain a systems perspective so as to arrive at the optimal APM design. The systems perspective views the APM as being a subsystem of the whole airport system. From this viewpoint, the APM is only a part of the most beneficial solution for the overall airport's configuration, functionality, user friendliness, and operational efficiency.

There are many different planning approaches that airports can follow, and have followed to date, when considering an APM system. The approach presented here is recommended as a good framework for an airport to consider. The organizational structure of an airport and its historical decision-making approach, its relationship with airlines and other airport tenants, and other factors will undoubtedly influence that airport's ultimate approach. Two good reference documents that provide the overall airport planning process are the FAA's advisory circulars entitled "The Airport System Planning Process" and "Airport Master Plans." In the United States, the FAA recommends that a master plan be completed and updated at appropriate times. This process ultimately results in an airport layout plan (ALP). It is good practice for airports planning an APM to incorporate an approximate alignment into the ALP.

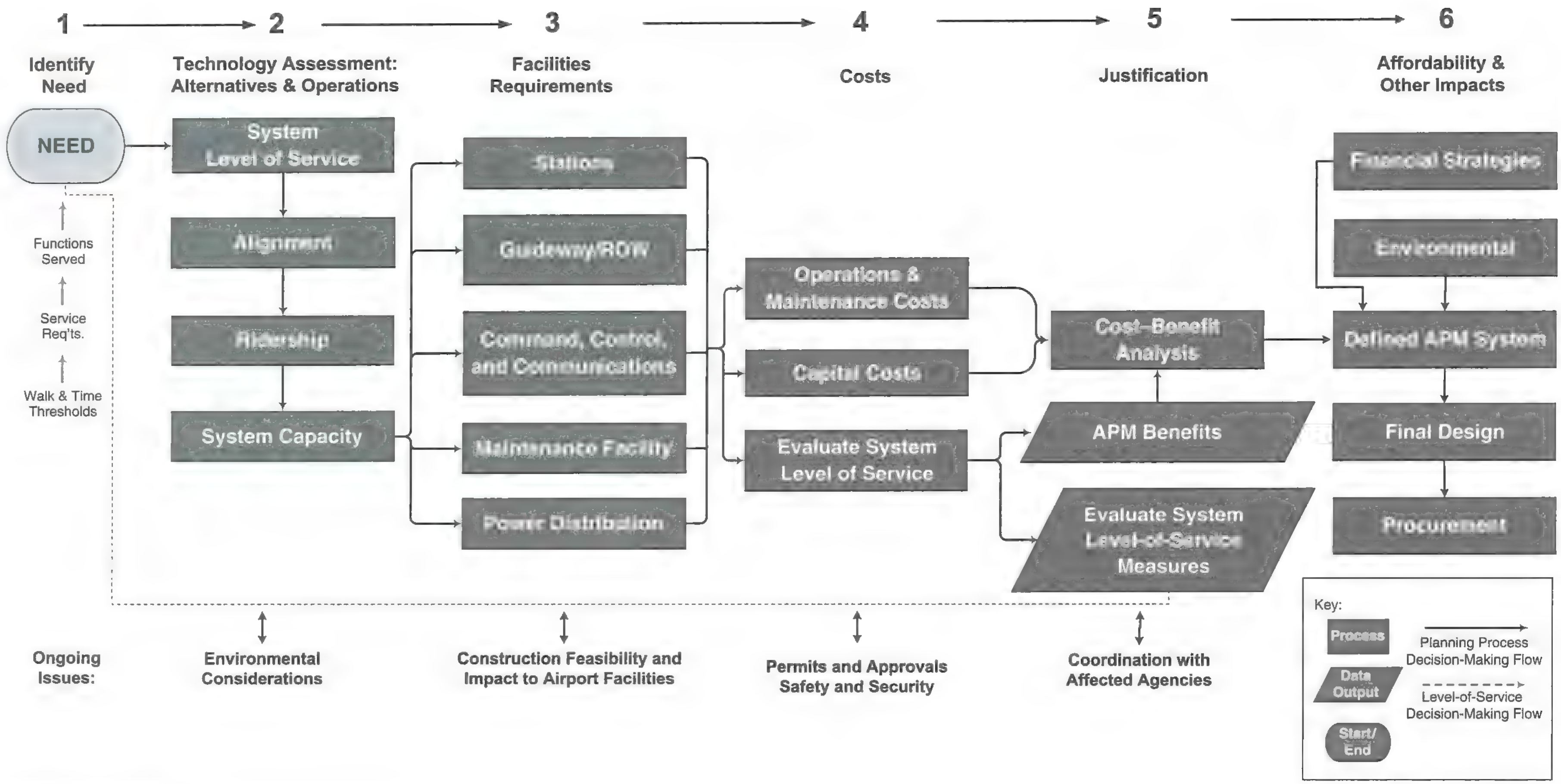
5.2 Airport APM Planning Process Steps

An air traveler's use of an airport facility requires the movement between multiple processes (ticketing, security, aircraft boarding). The movement between process locations may require conveyance assistance to ensure acceptable walk distances and/or movement times. The conveyance requirements at a major airport, whether on the airside or landside of that facility, can vary widely among airports and can vary in terms of distance and time at a single airport. Similarly, airport and airline employees have conveyance needs within the airport as they commute to/from their work.

The APM planning process is broken down into six sequential steps, as shown in Figure 5.2-1. There are also various ongoing issues that require the airport's attention and action throughout the APM planning process.

The first and most important step in airport conveyance planning is the establishment of acceptable limits or thresholds for walk distances and connection times between processing locations. When a walk distance or walk time threshold is exceeded, then the need for passenger conveyance technology is identified. This need becomes the starting point of the planning process (Figure 5.2-1) that may ultimately lead to the implementation of an airport APM.

Various passenger conveyance technologies such as moving walks, buses, and APMs all offer different levels of service. Determining the most appropriate technology among these groups is discussed in detail in Chapter 7 of the guidebook. If one or more of the above preliminary indicators suggest that an APM might be justified, further analyses are required to develop, analyze, and compare one or more candidate APM and other potential solutions. In so doing, many planning and feasibility issues must be addressed.



Source: Lea+Elliott, Inc.

Figure 5.2-1. General APM planning process.

A comprehensive APM alternatives analysis is an undertaking that requires extensive experience to complete properly. As a consequence, airports typically solicit the assistance of experienced professionals who have the requisite expertise. It is important that airport staff, planners, and other consultants understand the nature of what is involved in order to direct and coordinate the APM investigations with other airport planning work properly.

The general steps involved in a transport technology planning effort are summarized below.

- **Step 1: Identify need**—This is the process by which passenger conveyance needs to/from airport passenger activity centers that cannot be adequately accommodated by walking are identified and quantified. Quantification typically takes the form of wait time, connect time, and/or walk distance requirements and thresholds.
- **Step 2: Technology assessment: develop alternatives and analyze operations**—The passenger activity generators identified in step 1 will help determine station locations. To connect the station locations, alternative routes/alignments are developed and analyzed with respect to operations. This can be done using a single or a variety of different technologies. The analysis of operations will help in sizing the fleet to meet the demand ridership between stations and in providing a system capacity (passengers per hour).
- **Step 3: Determine facilities requirements**—The fleet size determined in step 2 allows the related APM facilities' requirements for power, maintenance, train control, guideway and its right-of-way (ROW), and stations to be developed.
- **Step 4: Determine costs**—With the alignment, fleet, and related facilities now sized, the high-level capital and O&M costs of the APM system can be estimated. The level of service (trip times, service frequency) can also be double-checked against relevant passenger conveyance thresholds from step 1.
- **Step 5: Perform justification analysis**—The costs developed in step 4 are then compared against the benefits of the system to determine if the APM is justified. Benefits can vary greatly in type between airside APMs and landside APMs but in either case should be monetized for this analysis. This analysis of costs and benefits is an internal airport analysis and is not to be confused with the standard FAA cost–benefit analysis.
- **Step 6: Determine affordability and other impacts**—The final planning step determines if the resulting APM system is affordable to the airport. Other final checks of environmental impacts, feasibility, and constructability (first performed during preliminary planning in step 3) are also performed in this final step. If all these checks come up positive, then the APM system enters final design and implementation (procurement).

It is essential to conduct APM planning in concert with the airport's overall planning process because the APM physically connects (and affects) other major airport facilities. These steps apply whether it is a multimodal (e.g., APM and bus) analysis or one that is focused on APMs only. In the multimodal analysis, the alternatives developed in step 2 are technology/route combinations. In an APM-only analysis, the alternatives are different alignments and possibly self-propelled versus cable-propelled technologies.

In addition to the above sequential planning steps, there are ongoing issues to be dealt with throughout the planning process. These are shown along the bottom of Figure 5.2-1 and include environmental considerations, construction feasibility, impacts to other airport facilities, required permits and approvals, and airport coordination with affected agencies.

During alternatives development (in step 2), it is important to consider the historical perspective of prior APM implementations, their successes, and failures. The lessons learned from experience can help develop and refine the number of alternatives. Similarly, knowledge of the current APM industry can help ensure that the alternatives developed are ones on which multiple, experienced APM suppliers with service-proven technologies can compete.

Upon completion of the above steps, it is recommended that the results be combined into a system definition report that will serve to document the analysis process.

Each of the above APM planning steps is described in greater detail in Chapter 8 and Appendix A, especially step 1 through step 4. Some of the more general (non-APM) analyses performed toward the end of the APM planning process, such as cost–benefit analysis, funding, and environmental impacts, are described in greater detail in Chapter 9.

CHAPTER 6

Needs Identification and Assessment

Chapter 5 provided an overview of the six steps involved in airport APM planning. This chapter goes into greater detail on step 1 (identify need—see Figure 6-1). Chapter 7 goes into greater detail on step 2 (technology assessment: alternatives and operations), in which transport systems are developed to meet the identified conveyance need.

Airports are where people transition between land-based transport and air-based transport. Within the confines of the airport, airline passengers have to travel various distances to accomplish their transition between land transport and air transport. Similarly, airport employees travel varying distances as they access the airport to reach their place of employment. As airline traffic has grown through the years, airports have grown in both physical size and in their passenger processing capacity. Though a portion of passenger and employee movements can be accomplished through unassisted walking, for larger airports, passenger conveyance technologies are required due to excessive distance and/or excessive passenger volumes moving in a constrained area.

When distances or passenger volumes require conveyance assistance, three basic technologies are typically considered: moving walks, APMs, or buses. APM is a category of transportation group encompassing very small vehicles (PRTs) to very large transit vehicles/trains. These conveyance technologies are further described in Chapter 7: Matching Needs with Passenger Conveyance Technologies.

6.1 Passenger Conveyance Need

The first step in the conveyance planning process is the identification of passenger movements that need conveyance assistance and warrant the initiation of formal planning studies of conveyance technologies. This step involves a specific assessment of current or future (particularly for an airport expansion) operational and physical conditions that could be improved or issues that could be resolved if a new passenger conveyance system were to be implemented within the airport. The justification for a passenger conveyance system can usually be resolving an airport access need, an airport circulation need, or a passenger movement and processing problem. The research produced from ACRP Project 03-14, "Airport Passenger Conveyance System Usage/Throughput," should be a useful reference on this topic.

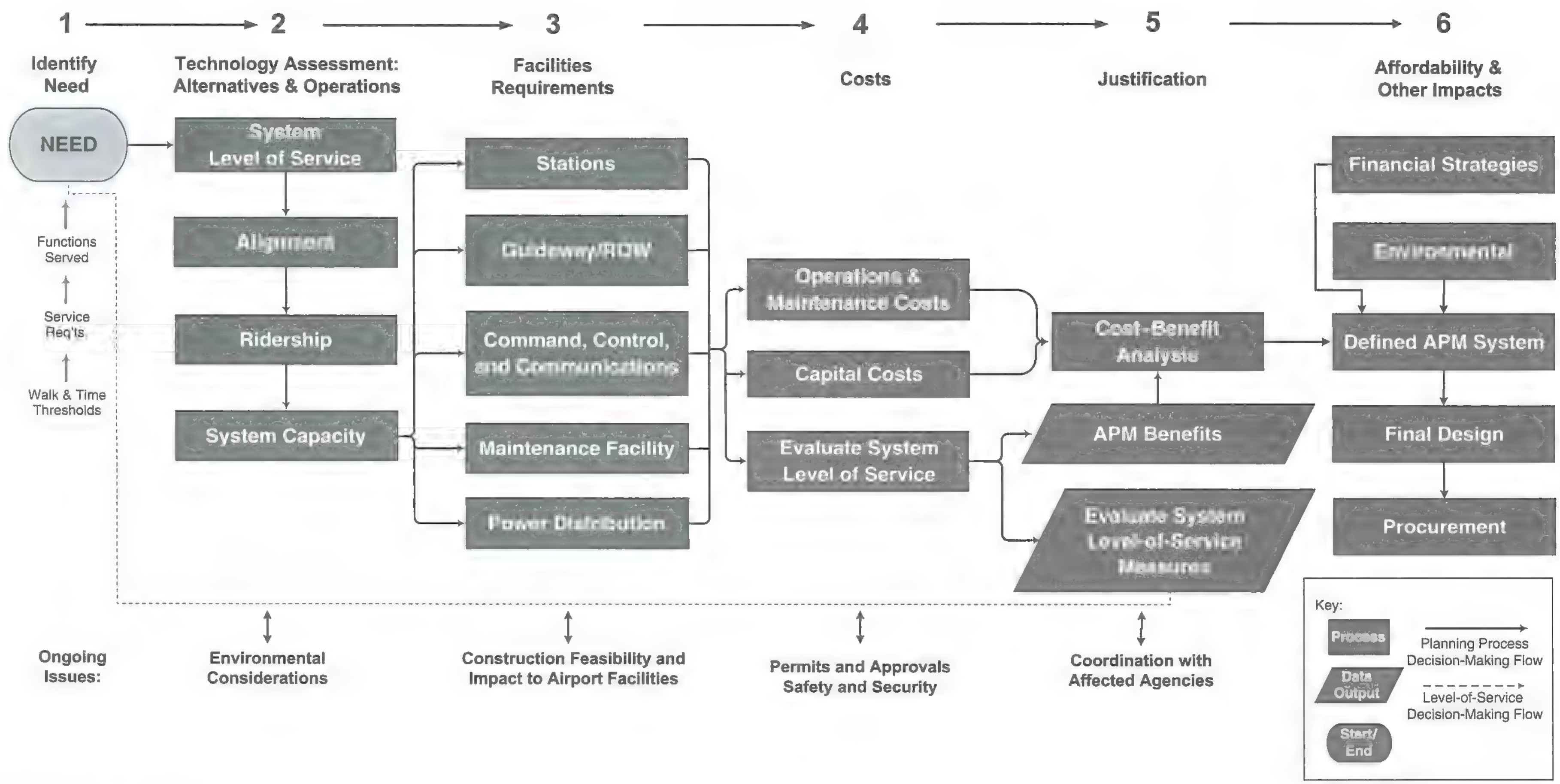
Airport issues and needs that have typically justified APM systems almost always involve the elements of distance and/or time, often in the context of physically separated facilities, which in turn directly affect the airport users' perceptions of the overall level of service offered by the airport.

The following are examples of airport conveyance needs that justify the analysis of passenger conveyance technologies including APMs:

6.1.1 Connection of Widely Separated Facilities

Wide separation of airside facilities is frequently required to service the large numbers and size of aircraft operating at major airports. On the landside, a wide separation of airport facilities is often created by the increased size of parking facilities, the relocation and consolidation of rental car facilities, or the location of bus or regional rail intermodal centers. This separation of facilities is a major factor driving the current design of new airports and airport expansions and the need for a high-capacity, high-quality, high-reliability (availability and trip time reliability) passenger conveyance option between the facilities.

Some new airport configuration concepts involve a physical separation of landside passenger processing facilities from airside processing facilities (aircraft gates and concourses). Also, many existing airports have constrained land space, with suitable expansion space being available only in remote locations on the airport property.



Source: Lea+Elliott, Inc.

Figure 6-1. General APM planning process.

6.1.2 Excessive Walking Distances for Passengers

The separation or expansion of airport terminal facilities often creates conditions where walking distances are greater than most airport passengers can easily negotiate. [Commonly, and according to International Air Transport Association (IATA) standards, this would be judged to be a distance of greater than 1,000 feet.] Many passengers are elderly and/or infirm, and most air passengers carry hand baggage. It is, therefore, becoming increasingly unrealistic to require passengers to negotiate long distances through airport facilities without conveyance systems.

6.1.3 Excessive Passenger In-Airport Travel Times

Travel times within airports are critically important to connecting passengers in large hub airports and increasingly important to O/D passengers due to unpredictable delays experienced in the check-in and security screening process. Hubbing airlines must be sure that connecting (online transfer) passengers move quickly from deplaning to enplaning gates within a specified time since the entire flight schedule is built around the time needed by passengers to make their connections. Airport operators want to ensure that their airport meets the expectations of O/D passengers so that they can complete their travel to/from their gate within reasonable times. To meet such expectations and operating requirements, passenger conveyance systems are often a necessity.

6.1.4 Segregation of Passengers

Current airport security has resulted in the mandated separation of some categories of passengers. These requirements vary for different sizes and types of airports. In some cases the resulting conditions can justify an APM or other passenger conveyance system to assist in the management and processing of the different passenger/airport user classifications. Common classifications of airline passengers/airport users that may require separation are:

- Secure and non-secure,
- International and domestic,
- Enplaning international and deplaning international,
- Sterile (unprocessed international arrivals) and non-sterile,
- Visitors (meeters and well-wishers), and
- Employees.

6.1.5 Improving Frequency, Capacity, and Quality of Passenger Service

To select the best mode, service issues such as waiting times, trip times, and capacities must also be considered. Because they are automatically operated, APMs can often provide headways below two minutes (if required), whereas buses are operationally constrained to much longer headways. (Buses can typically achieve very low headways if multiple bus berths are available; such an operation will have relatively high labor costs.) Studies have shown that passengers regard waiting time as much more onerous than travel time. Thus short headways (frequent departures/short wait times) are perceived by passengers as providing a much higher level of service. Short headways also translate into higher passenger-carrying capacity (for a given conveyance unit size), an attribute that is extremely beneficial in today's high-volume airports. APMs can also provide passengers' seamless connections between activity centers, a climate-controlled environment without exposure to the elements, and boarding and alighting the vehicle without vertical steps.

6.1.6 Reduction of Operating Expenses

Life-cycle costs are heavily affected by operating and maintenance expenses, especially at airports with long hours of service. Frequently, the life-cycle cost of an existing conveyance service such as buses can be greater than those of a totally new, automated system. When considering both capital costs and operating expenses over the life of a project, the benefits of lower annual operating expenses could provide justification for an APM system.

6.1.7 Passenger Safety or Security

In some circumstances, concerns about passenger safety or security could justify consideration of a landside APM system. A safe, secure form of passenger screening at remote sites (rental car facility, parking, intermodal transit station) served by APMs can increase the safety of the terminal environment, even if the screenings consist only of passive observation and random checks. Full check-in or bag claim is usually not provided at remote sites served by an APM, so passengers take all their baggage on the APM.

6.1.8 Serving Multiple Functions

For landside systems especially, an APM that serves multiple functions (activity centers) such as car rental, passenger and/or employee parking, regional rail, and so on is more easily justified than a system serving just one function. A multifunction system will be supported by more groups within the airport organization and potentially outside the airport in the case of serving a regional rail facility.

The first step in a passenger conveyance decision-making framework is to examine the various justifications, some of which are sampled above. Usually, a cursory examination will indicate if one or more is applicable. If so, then more detailed

planning and evaluation of various conveyance technologies (moving walk, bus, APM) is warranted.

6.2 Establish System Requirements

Several basic system requirements must be established at the outset of any APM investigation. It is important to note that an APM investigation is typically undertaken in response to the overall airport planning vision, and that a desire to build an APM does not drive the overall airport planning process. The basic APM system requirements are discussed below.

6.2.1 Functional Requirements

Defining the functional conveyance requirements for the APM is typically the very first step in the investigation. It defines the purpose of the system and answers the basic question: Do we need an APM? The principal functions of APM systems at airports are typically:

- **Inter-terminal connections**—Many APMs are designed exclusively for transporting riders between multiple terminals at an airport.
- **Terminal-to-gate connections**—Such systems are designed to connect terminal passenger processing areas to aircraft gates, which are often located in separated satellites, concourses, or piers.
- **Intra-terminal connections**—Conveyance systems may also serve the purpose of transporting air passengers and airline/airport employees between different areas of the same terminal or satellite facility.
- **Airport access connections**—These systems are designed to transport passengers between the airport terminal(s) and an access location of some kind—a rail station, a bus terminal, off-airport parking, or other passenger gathering point.
- **Landside connections**—Landside conveyance applications typically connect the terminal facilities with other on-airport landside functions such as car rental and passenger/employee remote parking.
- **Commercial development**—A landside conveyance application can also provide connections to office buildings, hotels, convention centers, and other commercial buildings located on airport property or property adjacent to the airport.

6.2.2 Desired Service Locations

Once the conveyance system's functions are determined, the next step is to identify the different airport elements (or service points) that require interconnection. Service may be required at points such as the main terminal(s), terminal piers, satellite concourses or terminals, parking areas, rental car facilities, and off-airport access locations (bus or rail terminals).

6.2.3 Physical Constraints

Defining physical constraints is a basic aspect of the planning process. For example, if the system alignment must travel from one side of a runway to the other, then it must either go around the end of the runway or beneath it. Physical constraints can dictate the guideway alignment, station and maintenance facility locations, and such factors as the maximum size of the allowable ROW for the system, the maximum radius of horizontal or vertical curvature, or in the case of a below-grade system, the minimum depth of the envelope below the runway surface.

When establishing a conveyance system's service locations and the route(s) to connect them, consideration must be given to spaces available for the system's maintenance and storage facility.

6.2.4 Pedestrian Requirements

All alternatives will have pedestrian components. Airport requirements involving pedestrian movement must be defined at the outset of the work. Pedestrian requirements may include:

- Walking distance limitations,
- Population mobility,
- Disabled and elderly provisions,
- Baggage carried,
- Baggage carts (and whether they will be allowed on the trains), and
- Level change limitations.

6.2.5 Level-of-Service Criteria

Criteria must be established for the level of passenger service that is desired. Primary criteria that will define the level of service experienced by passengers include:

- Maximum allowable connecting time for passengers,
- Maximum time passengers have to wait for a train,
- Seating provisions on the conveyance,
- Ease of locating system and navigating its use,
- Passenger comfort and convenience, and
- Overall passenger trip experience.

Other criteria may be applicable or desirable for specific airport conveyance applications. Some of the above level-of-service criteria can be expressed quantitatively, and this should be done where possible. Others are more qualitative, but they

should also be identified and used in the subsequent evaluations and assessments.

6.2.6 Types and Characteristics of System Riders

All potential conveyance system riders must be identified. Typical airport riders include:

- International passengers, including arriving, departing, and transfer;
- Domestic passengers, including arriving, departing, and transfer;
- Airline flight crews;
- Airport and airline employees; and
- Visitors, including meeters/greeters, well-wishers, and others.

It is important that the characteristics of all riders be defined, including the baggage they carry and the need for separation from other types of passengers. Although requirements differ for each airport, it is often necessary to consider maintaining separation between the following classes of passengers:

- International and domestic,
- Arriving and departing,
- Sterile and non-sterile,
- Secure and non-secure,
- Originating and terminating/transfer, and
- Employee and non-employee.

6.2.7 Allowable Environmental Impacts

Environmental impacts of proposed conveyance improvements are very important in airport settings. Requirements should be established for acceptable noise, air pollution, water quality, roadway traffic, and other impacts. In general, APMs will be a considerable improvement over any roadway-based form of transportation. Concerns or standards regarding visual impacts and aesthetics should also be defined.

6.2.8 Safety and Security Requirements

The aviation industry's focus on safety and security mandates that such considerations be included in the requirements and evaluation of any new airport system. This is especially true with APMs, where the system will be operated without an attendant on board the trains. Whether the APM is located airside (beyond security screening) or landside (before security screening) also makes considerable difference in the safety/security concerns that need to be addressed. In particular, requirements related to terrorist threats and fire need to be developed, including provisions for emergency evacuation of passengers from the conveyance system in times of danger.

6.2.9 Budgetary Constraints

Airport budget(s) for the project must be included as a project requirement since monetary constraints can affect subsequent decisions and choices in the development and comparison of alternatives of the overall terminal configuration and design as well as potential conveyance system(s).

Upon completion of the above tasks, it is recommended that the results be combined into a system requirements report that will serve as the basis for developing and evaluating all candidate alternative solutions.

6.3 Develop and Analyze Alternatives

Once the system requirements are established, it is necessary to move on to step 2 of the APM planning process chart (Figure 6-1) and develop and analyze candidate alternative solutions. An increasingly popular technique for the development of alternatives is to conduct a workshop involving a variety of people from various airport departments and consultant teams. The first phase of the workshop is to brainstorm the options for the conveyance system, with a record kept of the various ideas produced during the workshop. Then the rough concepts developed through the workshop are studied further by an assigned study team. Once the concepts are assessed for their intrinsic strengths and weaknesses, they are refined and developed into specific project alternatives to be studied in significant detail.

Alternatives may be different APM alignments, or the conveyance technology may be varied. The next chapter describes the typical conveyance technologies considered by major airports. Regardless of the technologies involved, it is critical that the range of alternatives be wide enough that all viable options are initially considered. An all-inclusive alternatives analysis helps prevent others from asking at the end of the APM planning process: "Yes, but did you consider . . . ?"

CHAPTER 7

Matching Needs With Passenger Conveyance Technologies

The prior chapter concluded with a brief discussion of step 2 of the APM planning process, developing alternatives to be analyzed with the objective of best accommodating the passenger conveyance needs identified in step 1 (see Figure 7-1). Alternatives in their most basic form are combinations of conveyance technology and route/alignment that connect the critical airport passenger activity centers.

The airside and landside passenger conveyance needs of major airports vary widely. Providing a high level of service to passengers is critical to all airports as they compete to attract customers in an increasingly competitive transportation environment. Larger hubbing airports compete with each other for connecting passengers, and all airports compete with rail, bus, and auto (and even other area airports) for regional traffic.

This chapter describes typical passenger conveyance technologies used at airports, both airside and landside. It then describes the typical airport airside technology evaluation process followed by the typical airport landside technology evaluation process. Finally, the chapter presents overall guidelines or thresholds to consider when evaluating the proper technology to use in meeting an airport passenger conveyance need.

7.1 Airport Conveyance Technologies

For conveying relatively large volumes of O/D airline passengers between aircraft gates and terminal functions (check-in, security, and baggage claim) as well as connecting transfer passengers between aircraft gates (both intra- and inter-terminal), there are three conveyance technologies typically employed: moving walkways, buses, and APMs. (For smaller passenger volumes and shorter distances, a smaller technology called "courtesy carts" is employed within airport terminal buildings. This technology is described in greater detail in ACRP project 03-14, "Airport Passenger Conveyance System Usage/Throughput.") These technology categories are listed in ascending order of system line capacity (passengers per hour per direction) for airside airport applications. They are described in terms of technical characteristics and by suppliers and their applications.

7.1.1 Moving Walkways

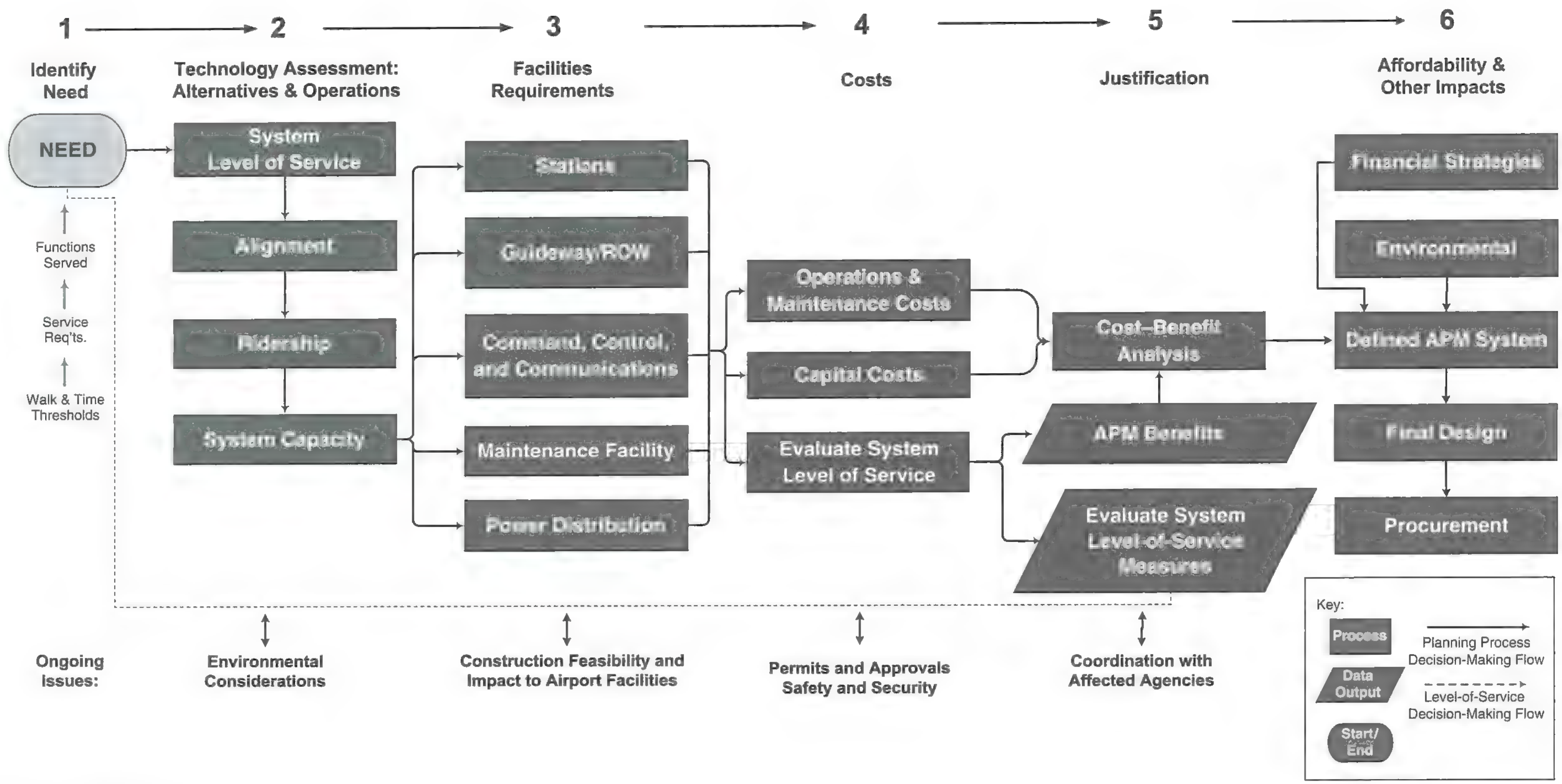
Moving walkways are a means of pedestrian transport that provide a flat or inclined continuous moving surface of pallets that convey passengers (standing or walking) and their baggage over moderate distances. These devices are popularly known as moving sidewalks, moving walkways, and travelators.

Typical walkway speeds range between 90 and 120 ft/min, or approximately one-half normal walking speed. The resulting passenger speed ranges from 90 ft/min (passenger standing) to 210 ft/min when passengers walk on the moving walk. Moving walkway lengths range between 30 and 500 ft, with pallet width ranges of between 24 in. and 55 in.

Passenger conveyance capacities for moving walkways are a function of walkway width, passenger density, passenger passing ability, walking/standing ratio, and the moving walkway's speed. For a typical airside airport application with carry-on baggage only, moving walk capacities range from 4,000 to 5,000 passengers per hour. For a landside airport application with baggage carts, moving walkway capacities range between 1,600 and 3,700 passengers per hour. Although the capacity of moving walkways is high, their slow speed often results in travel times that are not acceptable.

7.1.2 Buses

Rubber-tired buses are a prevalent form of transit at many airports around the world. At-grade bus operations are favorable because they are able to reach a variety of passengers and destinations with good flexibility and lower costs.



Source: Lea+Elliott, Inc.

Figure 7-1. General APM planning process.

Standard buses—Typically, these are driver-operated, diesel-powered, 30- to 40-passenger buses. Bus lengths range from 35 ft to 40 ft. System capacity can range from 400 to 500 passengers per hour, assuming five-minute headways.

Articulated buses—These driver-operated, diesel-powered, 50- to 60-passenger buses typically would serve an airport's long-term parking. Bus lengths are typically 50 ft to 65 ft. System capacity can range from 600 to 700 passengers per hour, assuming five-minute headways.

Buses are very flexible; routes and stations (stops) can be changed or added easily. Maintenance can occur either on-airport or off-airport. Bus lengths typically average 45 ft, and bus width is 8.5 ft for regular transit buses or up to 10 ft for specialized airport apron buses. These wider apron buses are not street legal and require special operations to transport them to off-airport maintenance facilities.

Buses operating on the airport apron cross active taxiways (where aircraft have the right of way) and thus can only achieve operating speeds well below their cruise speeds. Apron buses are typically 45 ft in length and can carry 80 to 100 passengers in an airside application (carry-on baggage only). For a typical airside airport application, a main terminal to remote concourse bus system with two separate routes serving the concourse at three-minute headways (each route) can achieve system capacities of 3,000 to 4,000 passengers per hour.

7.1.3 Automated People Movers

APMs are fully automated, driverless vehicles operating on fixed guideways along an exclusive right of way. APMs are divided into two major groups: cable-propelled and self-propelled. Monorails, rubber tire, and larger steel-wheel vehicles are considered within the self-propelled group.

Cable-propelled—This type of technology consists of medium- to large-capacity vehicles or trains using cable propulsion with various suspension systems. System line speeds of 30 mph can be achieved with longer station-to-station distances, but typical airside station-to-station speeds average 20 mph. The fixed-grip technology is best suited for two- or three-station shuttle applications with relatively straight guideway alignments of one-half mile or less. Beyond this distance, the time between trains can exceed an airport's desired level of service. Detachable-grip is a relatively new advancement in the technology that allows for more than two trains to operate simultaneously.

Self-propelled—Self-propelled vehicles or trains use a two-rail guideway system with rubber tires on concrete or steel wheels on steel rails. Depending on the supplier's technology, system maximum speeds range between 30 and 45 mph for longer station-to-station distances, but the typical airside station-to-station speeds are 30 mph.

Detailed descriptions of APM systems and technology are provided in Section 4.3. System capacity for airside APMs in a major airline hubbing operation can reach 8,500–9,000 pphpd, assuming 75 passengers per vehicle (passengers with carry-on baggage only), four-vehicle trains, and two-minute headways. Capacity requirements on the landside of an airport are typically lower than the airside capacity mentioned above. The upper end of the landside capacity range can reach 3,000 pphpd assuming 50 passengers per vehicle (all baggage), three-vehicle trains, and three-minute headways.

7.2 Airside Technology Evaluation

The appropriate passenger activity level at which to implement an airside conveyance technology varies by airport and can be influenced by a number of different factors. For APMs, which provide high capacity and level of service at a relatively high cost, there are certain thresholds that typically must be exceeded before a system is justified.

With some factors the thresholds are quantitative, while with others they are more qualitative. The importance of any single factor can vary greatly by airport. The typical factors that influence airside APM implementations include:

- Terminal configuration and geometry,
- Passenger level of service,
- Ridership volumes, and
- Costs and benefits.

These implementation issues are examined in detail below. This examination is based in large part on a survey of fourteen major U.S. airports with a wide range of airside conveyance needs and technologies.

7.2.1 Terminal Configuration Geometry

An airport's terminal configuration and its geometry have significant influence on the appropriate airside conveyance technology. A terminal configuration differentiator is whether the facility is contiguous, with a single structure housing the processing (check-in, security, baggage claim) functions and all airline gates, or whether it has multiple terminals, one or more with processing functions and one or more being remote with airline gates only.

Airports with contiguous terminal configurations tend to have moving walks for passenger conveyance. A limited number also employ APMs (but not buses) for passenger conveyance when an airline hubbing operation is present. Contiguous configurations are often referred to as letter-

shaped (such as "D" or "E") or as a spoke configuration. Different contiguous terminals vary widely in their configurations and are typically a function of property constraints and roadway access.

Airport terminal configurations with concourses that are remote from check-in, security, and baggage-claim functions typically have APMs (elevated or underground), often in conjunction with moving walks. A limited number of remote configuration airports use apron buses to connect facilities. In all cases these inter-facility conveyance systems include O/D passengers, and in some cases they include transfer passengers. The distance between the facilities influences the choice of conveyance system, with shorter distances accommodated by moving walks, medium distances by APMs or apron buses, and longer distances typically by APMs only.

Some airports have both contiguous terminals and remote terminals, such as Seattle/Tacoma and Miami. Examples of remote configuration airports using only APMs include Tampa, Orlando, and Denver. The airports with the shorter connections to remote terminals (Tampa and Orlando) have elevated APMs, which cost less to construct than underground APMs. Airports with longer connections to multiple remote terminals (Cincinnati, Denver, and Atlanta) have underground APMs that travel below aircraft taxilanes.

Airports employing a combination of APMs and moving walks include Atlanta and Cincinnati. Airports using apron bus systems to connect facilities include Washington Dulles (with moving walks) and Cincinnati (with APM and moving walks). Since Washington Dulles plans to build future remote (parallel) concourses further from its main terminal, it has recently opened an underground APM that replaced most of its current apron bus (mobile lounge) system.

The survey of fourteen major U.S. airports found a number of terminal configuration and geometric thresholds in terms of the airside passenger conveyance technology. Findings included:

Distance between Main Terminal and the Furthest Concourse

- For over 3,000 ft, APMs are the only conveyance technology employed.
- For 1,500 to 3,000 ft, apron buses and APMs are employed.
- For under 1,500 ft, moving walks are the dominant means of conveyance.

Number of Connecting (Hubbing Airline) Gates

- For more than 60 gates, APMs and buses are employed to connect the gates.
- For 30 to 60 gates, a mix of all conveyance technologies is employed.
- For fewer than 30 gates, moving walks are predominately employed.

7.2.2 Passenger Level of Service

The passenger level of service, typically measured in terms of walk distance and trip time, influences the choice of passenger conveyance technology. For O/D passengers, these distances and times are measured between security/baggage claim and the average and furthest aircraft gates. For transfer passengers, the distances and times are measured between the average and furthest connecting airline gates. Connect time between the two furthest-spaced connecting gates is critical because the Official Airline Guide sets a minimum connect time between arriving and departing flights that an airline can ticket a passenger as a transfer.

The walk distance and trip time data from the airports surveyed did not present clear differentiation between conveyance technologies. A maximum walk distance between security and the furthest gate, of approximately 2,000 ft, was found among all the airports and thus appears to be a threshold of acceptable level of service. When a given airport configuration reaches this threshold and still desires growth, the solutions have included the construction of remote concourses served by either APMs or apron buses, or extending the main terminal's curb frontage to serve the additional gates.

For airports with remote concourse gates served primarily by APMs and secondarily by corridors with moving walks, the walk distance savings for the trip between security and the furthest gate is approximately 50% when using an APM, or between 1,500 and 4,000 ft of walk savings.

Other differentiators among the airside conveyance technologies are level changes and exposure to the elements. The use of moving walks does not require a vertical level change, while use of apron buses and underground APMs does require such a change. Elevated APMs (such as Tampa and Orlando) do not always require level changes. APMs and moving walks also have the advantage of not exposing passengers to the elements while boarding or alighting the system. However, most apron busing operations do expose passengers to the elements, one exception being the mobile lounge system at Washington Dulles.

7.2.3 Ridership Volumes

As described by example in Section 7.1, the maximum passenger volume capacities that the different technologies can achieve on the airside of airports is as follows:

Moving walkways:	4,000 to 5,000 pphpd
Apron buses:	3,000 to 4,000 pphpd
Automated people movers:	8,500 to 9,000 pphpd

APMs are designed to better accommodate high hourly volume with level boarding, multiple doors, and wide door widths. By comparison a bus operation is constrained by the

number and location of bus berths; also, the technology requires steps in boarding and has a much lower door-width to vehicle-length ratio. Moving walk systems are supplemented by connector or concourse walk corridors parallel to the moving walks. Moving walk capacity can be substantially reduced by relatively slow passengers or passengers with baggage that block the passing lane on the moving walk.

The survey of fourteen major U.S. airports found a number of passenger volume thresholds in terms of the passenger conveyance technology employed at an airport. Findings included:

MAP Connecting

- For more than 20 MAP connecting, APMs are predominately employed.
- For more than 20 MAP connecting, moving walks are predominately used.

Hourly Passenger Volumes

- For more than 3,000 pphpd, APMs are predominately employed [exceptions include Chicago O'Hare (moving walk)].

7.2.4 Costs and Benefits

Every airport has its own unique set of geometric constraints to growth: from existing runway locations on the airside to existing roadways and other property owners on the landside. The relative strength of each of these constraints at a given airport, in conjunction with the passenger conveyance technology's performance characteristics, determines the best option for an airport's facility growth plan.

The capital and operating costs of any conveyance system must be financially feasible for the airport. These costs need to be considered in the short and long term as the most affordable technology (bus versus APM) can change depending on the financial time frame.

The capital and operating costs of airside conveyance technologies vary widely. Indirect costs can apply to the technologies as well. Dual-lane moving walks increase the width of a concourse by approximately 11.0 ft, and some airports have installed four parallel moving walk lanes. Buses require a maintenance facility, which may occupy valuable airport property. System equipment costs and annual operating costs range from relatively low for buses, to moderate/high for moving walks, to high for APMs. Facilities costs include the system's elevated or tunnel structure (moving walk or APM), maintenance facility (bus or APM), and stations (bus or APM). Facility costs typically exceed the system equipment costs and vary widely by region.

On the revenue side of the equation, aircraft gates translate into airport revenues. All three conveyance technologies help to connect distant gates with main terminal processing and/or other connecting gates by reducing the walk distance and travel time between the two locations. Thus the technologies allow for more gates to be used while still adhering to level-of-service thresholds for walk distance and trip time. The faster the technology conveys passengers, the more gates a technology allows an airport to use. For hubbing operations, a strong correlation was found between the number of connecting gates and the conveyance technology, as summarized below.

Aircraft gates for a hubbing airline operation have higher gate utilization and therefore generate greater revenues for the airline and airport. Also, hubbing (connecting) passengers do not require landside facilities. Hence, many airlines/airports have been able to justify remote terminals connected by APMs on a cost/benefit basis. The APMs have allowed an airport to turn otherwise nonperforming land into revenue-generating property, placing more terminals farther away and handling greater numbers of annual passengers.

APMs have also allowed contiguous terminal configurations to be converted into major hubbing operations (Dallas/Fort Worth and Miami). Chicago O'Hare and Newark use landside APMs to connect international terminals with domestic ones and increase both their international and domestic traffic volumes.

7.3 Landside Technology Evaluation

Just as no two airports are exactly alike, the appropriate time or activity level to implement a specific landside conveyance technology varies by airport and can be influenced by a number of different factors. For APMs, which provide high capacity and level of service at a relatively high cost, there are certain thresholds that typically must be exceeded before a system is justified.

With some factors the thresholds are quantitative, while with others they are more qualitative. The importance of any single factor can vary greatly by airport. The typical factors that influence landside APM implementations include:

- Passenger/employee volumes,
- Facility spacing,
- Terminal access spacing,
- Terminal roadway capacity,
- Regional rail station proximity,
- Costs and revenues,
- Airport land use and revenues,
- The airport's desired transport level of service, and
- Competitive position to rival airport.

7.3.1 Passenger/Employee Volumes and Facility Spacing

In surveying airports that have implemented landside APMs, an overall measure such as MAP for O/D passengers does not

provide a clear threshold for implementations. Airports with landside APMs range between 12 MAP and 30 MAP of O/D passengers at the time of implementation, with a concentration around 22 MAP.

A better passenger metric is the design hour volume. APMs are designed to better accommodate high hourly volume with level boarding, multiple doors, and wide door widths. By comparison, a bus operation is constrained by the number and location of bus berths, and the technology requires steps in boarding and has a much lower door width to vehicle length ratio. As shown in the Figure 7.3-1, landside APMs can potentially move over 6,000 pphpd, while a bus system often has difficulty accommodating flows over 2,000 pphpd at a single location with any fewer than four bus berths.

For current APM systems connecting a main terminal with (1) other terminals, (2) car rental, (3) long-term parking, and (4) regional rail, system demands are in the hourly range of 2,500 to 3,500 pphpd. APM systems serving all these groups tend to be longer systems of between 2 and 3 miles. Systems serving fewer than the four groups listed above have proportionately lower demands and are typically shorter in length. Systems serving only car rental and long-term parking may have hourly demands from 1,000 to 2,500 pphpd and range from 1,500 ft to 2 miles. For remote facilities located more than three miles from the main terminal, buses are the more typical transport technology. It should be noted that for the purposes of the survey, the nine-mile Airtrain at New York's JFK International is considered a regional rail system extension rather than an airport landside APM.

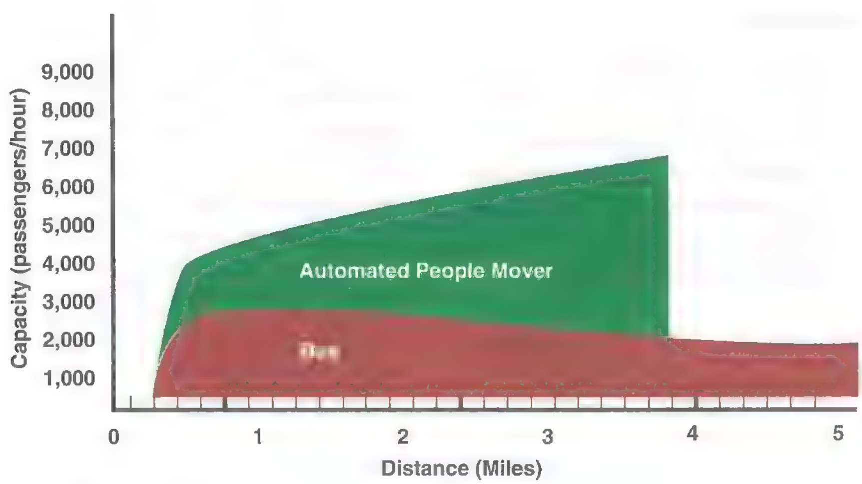
For existing landside systems, the hourly number of passengers per mile of dual-lane guideway is another threshold to apply. The longer 2- to 3-mile systems tend to have design hour flows of 500 to 700 passengers per mile. Shorter systems of 1,500 ft to 2 miles, though serving fewer rider groups, typically have higher flows of 700 to 1,200 passengers per mile.

7.3.2 Terminal Access Spacing

Longer landside APM systems (length of guideway) typically serve multiple landside terminals, each having their own ticketing and baggage-claim functions. One of the APM's main functions is to connect these terminals. Connecting a terminal with international service to one or more domestic terminals occurs at a number of landside applications, including Chicago O'Hare, Newark, Frankfurt, San Francisco, and Paris–CDG. For those gate-to-gate connections, passengers must go out of and then back through security screening. As an implementation criterion, when terminal access locations are spaced 1,000 ft or more from one another, APMs or buses, as opposed to moving walkway connections, are typically used to provide connections between the terminals. *ACRP Report 25: Airport Passenger Terminal Planning and Design* is a helpful resource on this topic.

7.3.3 Terminal Roadway Capacity

Terminal roadways can quickly become a landside bottleneck, resulting in long delays for buses and autos. Lengthening or widening terminal roadways eventually becomes physically impossible, if not cost prohibitive. At airports such as Newark, Chicago O'Hare, Düsseldorf, and Birmingham (UK), landside APMs provide an efficient means of supplementing the terminal roadways, thus improving access to and from the terminal buildings. These landside APMs allow the airport to increase passenger volumes without having to increase roadway capacity. With this factor there is probably not a universal roadway



Source: Lea+Elliott, Inc.

Figure 7.3-1. APM and bus capacities.

capacity threshold. At individual airports a high demand/capacity ratio over a sustained period is probably a better metric.

7.3.4 Regional Rail Station Proximity

Most major airports desire to have a regional rail station located within the terminal complex, allowing an easy connection between the rail station and ticketing and baggage-claim functions. However, many major airport terminal functions are not served well by a single rail station location. Also, regional rail's geometric constraints (curves and grades) do not easily allow multiple station locations in the terminal area. As a consequence, the cost and constructability impacts of in-terminal station location(s) have led some airports to locate a regional rail station remote from the terminal area.

With the more distant locations from the terminal, APMs and buses provide the connection to the terminal. Passenger arrival patterns at the regional rail station depend on that service's train frequency and train size. Long trains arrive periodically and unload a large group of passengers in a very short time period. Such surged demand is well suited to the high capacity provided by APMs.

The majority of airports surveyed have their existing or planned (future) regional rail station between 200 and 1,000 ft from their terminals. These are almost exclusively served by walkways. APMs serve a small number of airport rail stations over distances between 1,000 ft and 2 miles between the station and the terminal. Buses serve a larger number of airport rail stations, with the distance between the station and the terminals ranging from one-half mile to 3 miles for most of these systems. The maximum distance served by relatively frequent bus service (30-minute headways) was approximately 12 miles. *ACRP Report 4: Ground Access to Major Airports by Public Transportation* is an excellent resource on this topic.

7.3.5 Costs and Revenues

The capital and operating costs of any conveyance system must be financially feasible to the airport. These costs need to be considered in the short and long term because the most affordable technology (bus versus APM) can change depending on the financial time frame. The implementation of a landside APM can positively impact costs and revenues for an airport. The following are examples of indirect financial benefits:

- APMs can lower construction costs and shorten schedules of terminal roadway expansion or short-term parking expansion by allowing remote garages to temporarily serve short-term parkers.
- APMs can reduce costs of regional rail service to an airport by allowing for a remote/at-grade airport station, as opposed to a terminal/below-grade airport station.
- Given the high correlation between an airport's parking pricing and parking proximity (time/distance/ease of access) to the terminal, the same remote garage could be viewed as closer and more convenient if served by APM as opposed to bus. Directness of route, shorter headways, and exclusive right of way all contribute to the APM's quicker connect times. This faster service can translate into greater parking revenues for a given garage.

7.3.6 Airport Land Use and Revenues

Major international airports have a wide variety of land uses on their premises. With airport growth, the expansion of terminals and roadways often force other facilities to relocate to more remote locations. Landside APMs have been used to facilitate such relocations at airports including Minneapolis/St. Paul, Düsseldorf, and Chicago O'Hare. APMs are most efficient when such facility relocations have high densities, such as with consolidated car rental and/or multi-story long-term parking structures. The higher densities allow a single APM station to serve a large number of facility users.

Commercial development opportunities on airport and adjacent properties are a revenue-generating land use that is under consideration for planned landside systems at Oakland and Phoenix. The ability of a landside APM to connect the airport facilities and a regional rail station with a commercial development property can enhance that property's value to the tenant, and hence, revenues to the airport.

The relocation of check-in and security processing away from the aircraft gates and baggage-claim functions is a new land-use issue under consideration at a number of major airports. Again, APMs are in the planning stage for this type of high-capacity facility.

7.3.7 Airport's Desired Conveyance Level of Service

The level of service provided by a landside conveyance technology can be measured in many different ways. Level-of-service measures typically include trip time, wait time, walk distance, weather protection, mode changes, level changes, and bag cart accommodation.

For example, weather protection was a major reason that Minneapolis/St. Paul implemented a relatively short 1,000-ft landside APM to car rental and parking garages in its extremely cold climate. The ability to accommodate baggage carts has been a very positive factor for APMs in comparison to buses for south Florida airports that handle high volumes of baggage-laden tourists bound for cruise ships.

A rider of a landside APM system can reasonably expect to save about half of the overall trip time between point A (e.g., station in parking garage) and point B (e.g., airport terminal

station) compared to a similar trip using a landside bus. The trip time savings come from shorter headways, faster average speeds, and more direct routes (APM alignment vs. airport roadway system).

7.3.8 Competitive Position to Rival Airport

For multiple airports run by the same agency or for multiple airports served by a single regional rail system, there may be political pressure for the airports to be served equally. Examples of this in the United States are in New York City and the Bay Area in California, where the decision of one airport to implement a landside APM helped lead another airport to an implementation of its own.

For multiple airports in a single region run by separate agencies, often there is fierce competition to attract passengers. Once again, when one airport implements a landside APM, the competing airport soon follows. For example, in a tourist-destination region of the United States, where two major airports compete for the same tourist/cruise passengers, two airports are currently in the planning or implementation stages of landside APMs that would help connect the airport to the seaport.

7.4 Airport Conveyance Technology Guidelines

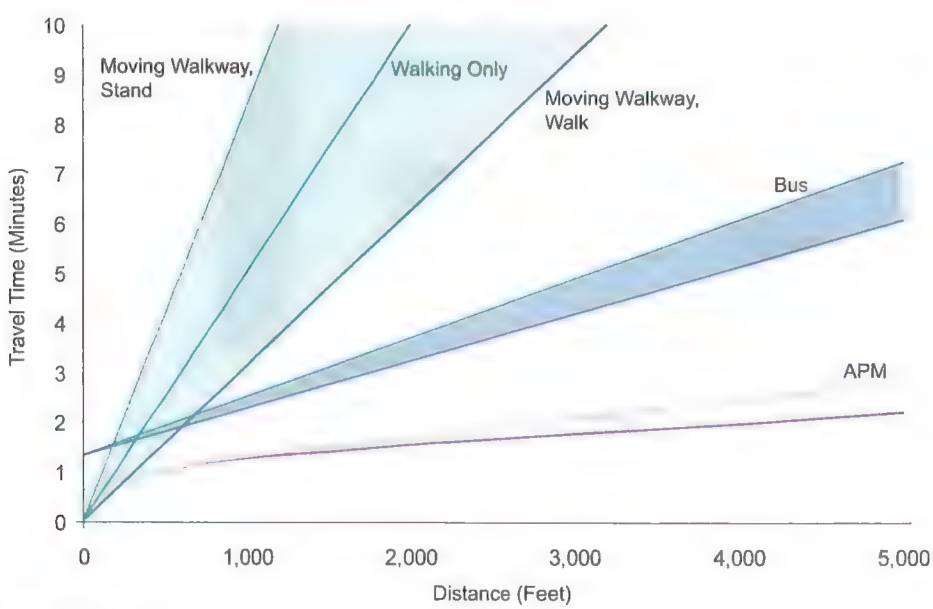
While this chapter attempts to quantify some general implementation thresholds for different passenger conveyance technologies, the most appropriate technology at a given airport is always the technology that best meets the goals and objectives of the airport. Given the many components of an airport's environment, the framing of these goals and objectives in a technology assessment must be comprehensive and inclusive. By properly framing the passenger conveyance analysis with full integration of the airport's goals and objectives, the best technology for the airport will emerge.

The most basic comparison of passenger conveyance technologies looks at the connection time between two locations for different separation distances. This connection time comparison is a typical level-of-service metric used in comparing the different technologies. Although such a comparison is very site-specific, results of a typical airside comparison are provided in Figure 7.4-1; the longer the distance, the greater the connect time advantage of an APM.

The speed advantage of APM systems has brought new expansion possibilities to existing airports and has allowed new terminal design concepts to develop, including increasing the number of gates and the distance between facilities while still meeting the airport's threshold for walk distance and connect time.

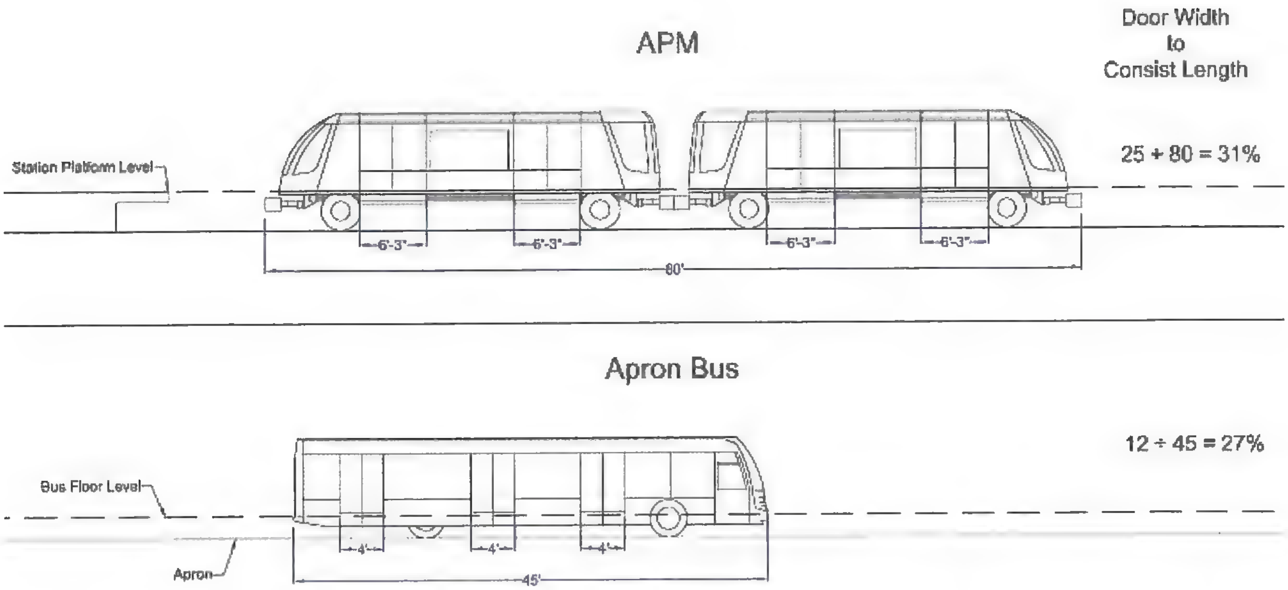
APMs also provide greater system capacity flexibility, measured in pphpd, than competing conveyance technologies. Greater alighting/boarding rates at a station compared to apron bus and conventional rail is one aspect of improved overall system capacity for APMs. In Figure 7.4-2, the ratio of a vehicle's door width to train consist length (vehicles making up a train) and the issue of level boarding versus step boarding are compared for APMs versus apron buses.

The typical APM train has a considerably higher ratio of door width to vehicle length; it also allows alighting/boarding on both sides of a vehicle, unlike an apron (or landside) bus,



Source: Lea+Elliott, Inc.

Figure 7.4-1. Airside technologies—travel time vs. distance comparison.



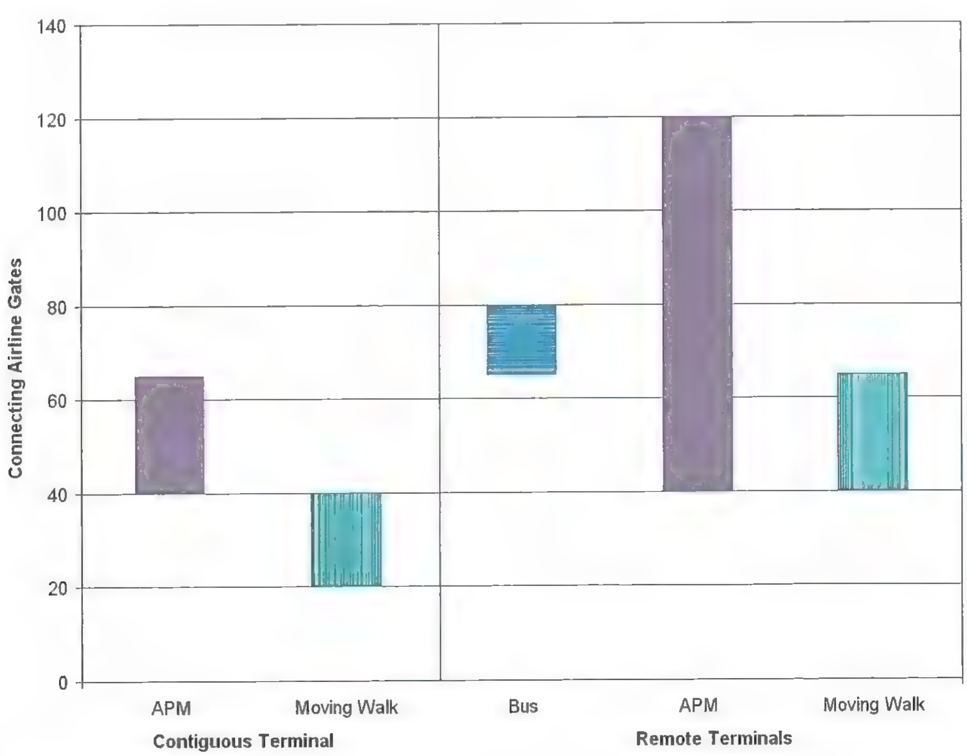
Source: Lea+Elliott, Inc.

Figure 7.4-2. Door width and boarding level comparison.

which typically can only access one side. The APM also has level boarding, which allows faster boarding compared to the step boarding of apron buses.

From the survey of fourteen major U.S. airports, some interesting airside correlations were found between the conveyance technology and the distance between facilities served. The type of airport terminal configuration was also found to influence the conveyance technology.

A comparison of the number of gates used by hubbing airlines against the type of airside conveyance technology is provided in Figure 7.4-3. As the figure shows, airside APMs allow greater airline hubbing (connecting) operations to take place



Source: Lea+Elliott, Inc.

Figure 7.4-3. Connecting gates vs. terminal type by airside technology.

regardless of the terminal configuration. For both contiguous and remote terminal configurations, APMs allowed for approximately 50% more gates.

A number of interesting trends and correlations have developed in the airside APM field since the first shuttle system opened at Tampa in 1971. The earlier airside applications tended to be shuttles, serving airports with mostly O/D passenger operations. Since the early 1990s, however, there has been a mix of shuttles and pinched-loop systems serving O/D operations as well as transfer or hubbing operations. With the pinched-loop operations have come longer APM systems with multiple airside stations.

CHAPTER 8

APM System Definition and Planning Methodology

Chapter 7 described the higher-level technology assessment where APMs are compared and contrasted with buses and moving walks for meeting the airport's conveyance needs. If the APM technology emerges from this assessment as the optimal technology and worthy of further investigation, then a planning-level APM system definition is performed.

This chapter describes the planning and analysis required to properly define an APM system within the airport APM planning context described in Chapter 5. These analyses relate to the APM planning steps 2 through 4 first described in that chapter. The APM system is defined in terms of alignment/guideway, ridership, system capacity, stations, other facilities, safety and security, level of service, and costs. The planning methodologies for each of these areas are described in detail. This system definition is initially sequential in nature. For example, decisions or results from the alignment analysis lead into the ridership estimation and from ridership estimation into the capacity/fleet sizing analysis, as shown in Figure 8-1 in step 2.

This chapter provides more detail about the APM planning methodologies used to define an APM system, whether airside or landside. Specific airside and landside examples of the APM planning process are provided in Appendix A.

8.1 Route Alignment and Guideway

8.1.1 APM Guideway Characteristics

The guideway of the APM system refers to the track or other riding surface (including supporting structure) that supports and physically guides vehicles that are specially designed to travel exclusively on it. The guideway structure may be provided by the APM supplier, as discussed in Chapter 10 (APM System Procurement).

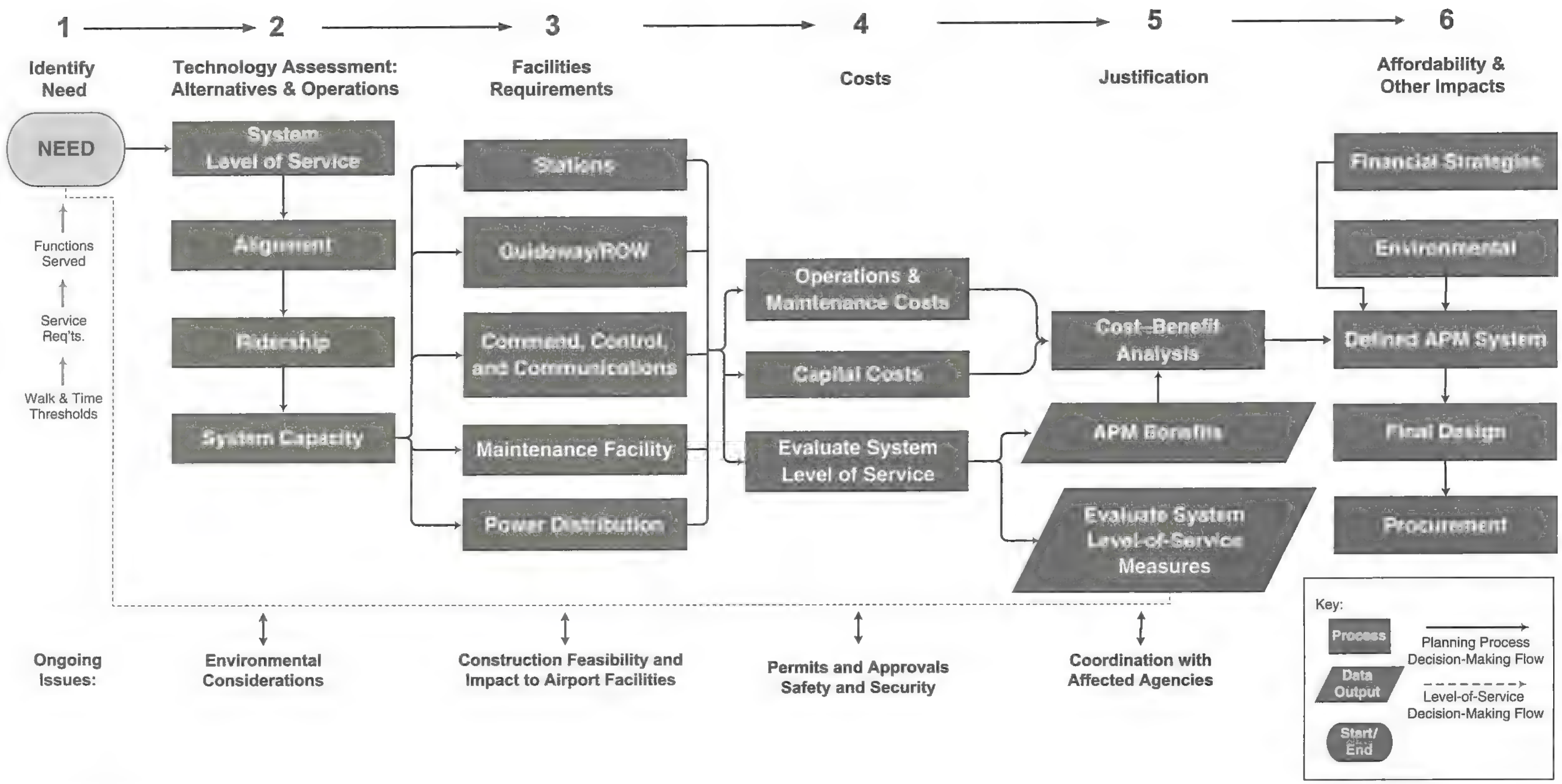
Photo: www.doppelmayr.com

Guideway Running Surface

The guideway can be constructed at grade, above grade, or below grade in tunnels. Depending on the selected supplier, the guideway can be constructed of steel or reinforced concrete. The size of the guideway structure (columns) varies with span length, train loads, and any applicable seismic requirements. Spans typically range from 50 ft to 120 ft in length.

The APM supplier provides guideway equipment that generally includes running surfaces, guidance and/or running rails, power distribution rails, signal rails or antennas, communications rails or antennas, and switches. For technologies that employ linear induction motors for propulsion, guideway equipment may also include either a reaction rail (the rotor) or the powered element of the motor (the stator).

An emergency walkway along the guideway is often required to provide emergency egress from a disabled train. It is typically continuous, preferably at vehicle floor height, and provides an unobstructed exit path to a station or other place of refuge or escape. Most emergency walkways are adjacent to the APM



Source: Lea+Elliott, Inc.

Figure 8-1. General APM planning process.

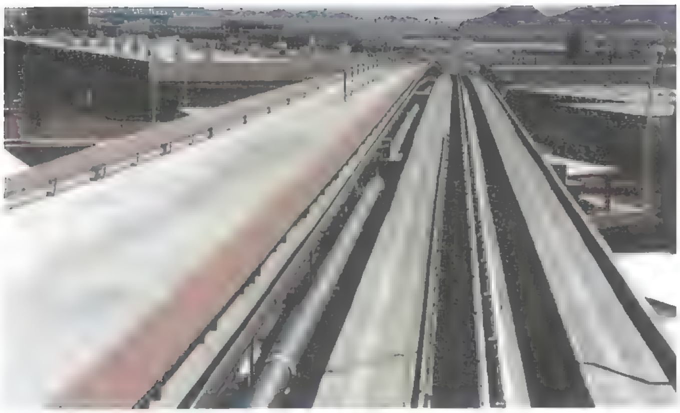


Photo: Lea+Elliott, Inc.

Emergency Walkway

guideway. Some APM systems allow for emergency egress along the guideway itself, with passengers evacuating from the front or rear of the train.

Crossovers or switches provide the means for trains to move between guideway lanes. They are required for pinched-loop operations and are also desirable for failure management purposes on such system configurations. Crossover requirements vary significantly among APM system suppliers, and each supplier's crossover requirements are unique in that their geometric requirements are largely inflexible. Many guideway configurations have guideway switches that allow trains to switch between parallel guideway lanes or between different routes on a system. Different APM technologies have different types of switches including:

- Rail-like,
- Side,
- Beam replacement, and
- Rotary.

Due to the guidance systems of most rubber-tired APMs, a crossover is generally composed of two switches (one on each guideway lane) connected by a short length of special trackwork. Steel wheel/rail APMs use rail switches, and one APM system uses a slot-follower switch that is similar to a traditional rail crossover switch.

8.1.2 Route Alignment Planning

Alignment planning involves developing alternative alignment options that provide the desired connectivity between activity centers/stations and then evaluating those options based on a range of criteria, including several that involve passenger level of service, such as:

Directness of passenger route—The directness of the route contributes to a passenger's perception that they are being taken on the shortest distance to reach their destination. The straightest path and fewest stops between a passenger's origin and destination will contribute positively to the passenger's experience. Circuitous routes (particularly onerous one-way loops) and many station stops create negative images of the APM and the facility it serves.

Trip times—Routes and geometry that allow good cruise speeds will help minimize travel (in-vehicle) times. Frequent train service is desirable as the lower headways (time between trains) result in shorter passenger wait time.

Passenger walk times and distances—The placement of stations should minimize passenger walk distances to and from gates and activity centers. Station locations should also minimize vertical level changes to the extent possible.

Ride quality—The geometry of the alignment should be as straight as possible to minimize the lateral and vertical forces imposed on the passengers. The use of superelevation in curves will minimize lateral forces imposed on the passengers and allow faster operating speeds.

Seamless connectivity—Passenger connections should be as seamless as possible, avoiding transfers between APM routes. When transfers are necessary, it is preferable to minimize walk distances, level changes, and passenger wait times for such transfers; cross-platform transfers are preferred.

Ease of use—Simple alignment and route configurations such as loops, pinched loops, or shuttles promote easy understanding for the passengers. Multiple route configurations can be confusing and complicate the passenger's trip. APM station and terminal signs (static and variable messages), route color coding, and other means should assist in passengers' understanding of the system.

Physical constraints—The planning of APM alignments sometimes must be coordinated with an airport's runway protection zone (RPZ) or its one engine out (OEO) surface. In the United States, the Federal Aviation Administration enforces the RPZ and OEO surfaces. It accepts or rejects encroachments for individual cases after review. A landside APM should be in the airport layout plant (ALP) [and could be subject to FAA approval, including needing an environmental impact statement (EIS)], and coordination with the FAA is important if the guideway or any other facilities are in or near the end of runway clearance zones and surfaces. Also, if the landside APM is closer than the 300-ft rule, the planner should coordinate with the Transportation Security Administration (TSA).

Simplicity of passenger wayfinding—Clarity of passenger signage and visual connections and other cues help to ensure that passengers move efficiently and will minimize confusion and back tracking.

Visual connectivity—It is preferable to provide opportunities for visual connections such as between stations and activity centers or among stations. The trip will seem shorter if passengers are able to see where they are going.

8.1.3 Alternative System Configurations and Operating Modes

Once the functional requirements and service locations for the APM are determined, alternative system configurations and operating modes must be developed. This work is a crucial aspect of the overall planning process because it will dictate the physical and performance characteristics of the APM and thereby be the principal determinant of the system capital and O&M costs.

Developing appropriate APM configurations requires in-depth technical knowledge of the candidate technologies and their capabilities and limitations. Layouts may range from simple shuttle(s) to open or pinched loops to complex networks employing switching and offline stations. Single or dual-lane layouts may be appropriate under different circumstances. Candidate system configurations and operating modes may be determined from experience and an assessment of the physical aspects of the airport. However, in every case, the best system layout and operating mode must be determined by detailed analysis and evaluation of various APM alternatives.

This phase of study usually involves advanced simulation tools that mimic the APM's propulsion and braking capabilities as well as the effects of the automated regulation of train separation, headway, and station dwell times. Such train performance studies allow the determination of the round-trip time and the travel time between each station in the system. In most cases, the best system is the simplest system that will fulfill the planning criteria. Complexity can increase costs and result in reduced system availability, and so should be avoided unless there are reasons for that complexity.

8.1.4 Guideway Geometry Criteria

The optimal APM guideway geometry would encompass a level, straight alignment. It would be at grade in order to avoid the costs of a below-grade tunnel or elevated structure. However, in real-world practice, this ideal guideway is difficult to attain. Some airports, such as those in Atlanta and Denver, have APMs that were initially designed and built in concert with the airport and were thus afforded straight, level guideway alignments. Often, however, the alignment must accommodate planned or existing physical constraints within an airport's existing environment. Also, the exclusive nature of the guideway, when introduced into a congested airport environment, seldom allows at-grade runs for any significant distance. Nevertheless, when planning an APM, attempting to achieve a level, straight guideway with at-grade sections remains a worthy goal. Such a guideway is simpler to design, construct, and operate on and thus may have positive cost implications. It also allows maximization of the trains' performance potential.

Deviations from a straight and level guideway have planning constraints that must be observed. The final APM guideway design must be done by a registered structural engineer having specific APM design experience. Although detailed guideway design techniques are beyond the scope and purview of this guidebook, general planning principles can be followed that will help ensure that the guideway geometry, as developed in the APM's planning phase, is a sound, feasible, and operationally and fiscally efficient preliminary design that can be carried into final design, construction, and operation.

The unique nature of each project must also be considered. The initial planning of a guideway should allow maximum flexibility to the airport as to the choice of technology. Two primary design options are available:

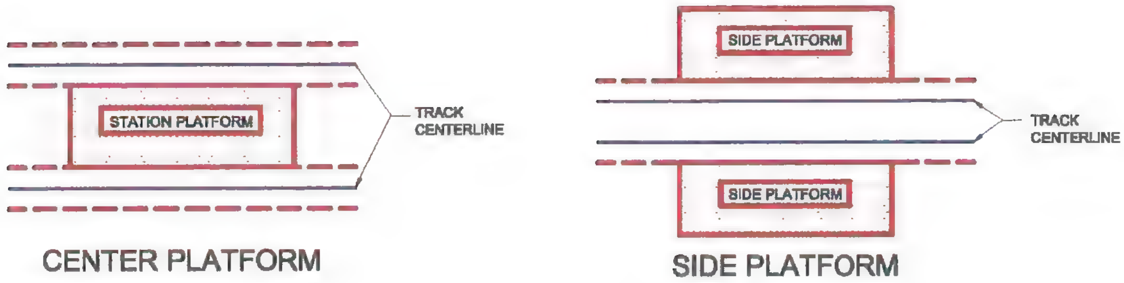
- **Right-of-way for multiple candidate technologies**—This is required for a traditional design-bid-build procurement approach, where the infrastructure is to be designed and built separate from the operating system, or for a design, build, operate, and maintain (DBOM) approach, where the infrastructure and operating system are procured together. Refinement to the initial guideway design is feasible within the parameters set by original planning, based on design level information for the selected APM technology.
- **Right-of-way based on specific technology/supplier**—This is anticipated in a sole-source procurement approach, or for an extension of existing system, or with the airport's prerogative to choose a technology in advance of planning based on a public–private partnership (PPP) or similar mechanism.

The preliminary planning and design criteria for the development of an APM guideway alignment can be broken into three areas: station area guideway, wayside guideway, and crossover area guideway. Each of these areas has a different purpose and goal and is treated differently for the most effective and economical solution.

Station Area Guideway

The primary purpose of the guideway in the station area is to align and interface the trains with the station. The configuration of the station (center platform or side platform) dictates the center-to-center distance between the guideway lanes for a dual-lane system as shown in Figure 8.1-1.

In order to get the maximum capacity of the APM system, the frequency of train departures should be maximized (minimize headway between trains). The crossover location for turnbacks should be as close to each of the terminal stations



Source: Lea+Elliott, Inc.

Figure 8.1-1. Station area guideway configuration.

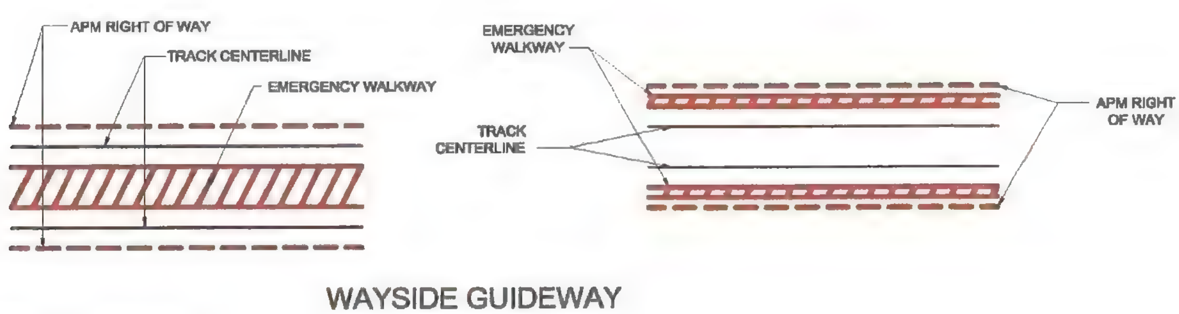
as possible to achieve minimum turnback times and thus minimum headways. This typically requires a constant track separation for a length of the track adjacent to the end-station. The planning should accommodate a minimum of 150–300 ft tangent track adjacent to terminus station prior to any horizontal curve in the alignment.

When planning the guideway configuration for an end-of-line station where trains reverse directions, the optimum location of the turnback guideway and switches should be examined. These guideway elements may either be located ahead of or behind the station platform. Typically the train-reversing guideway elements are located ahead of the platform, as shown in Figure 8.1-2. This configuration requires the minimum amount of guideway and provides the shortest round trip time. However, it is possible in some instances that worthwhile benefits may accrue from locating the train-reversing guideway elements behind the platform, as shown in Figure 8.1-3. Although this configuration requires more guideway and has a greater round trip time, it is possible, depending on the overall station geometry, that locating the train-reversing elements behind the station platform may allow shorter train headways and thus higher system capacity. Since additional costs (e.g., guideway, switches, tunnel length, fleet) are associated with this decision, the above issues are best examined using computer simulations of train movements over the specific guideway geometry and dimensional alternatives.

Wayside Guideway

The primary purpose of the wayside guideway is to move the APM trains through a dedicated corridor with exclusive right of way. Due to the configuration of the power distribution and frequency of the APM trains, these systems do not allow grade crossings or interface with any non-APM functions within the guideway. The tightest spacing of the adjacent tracks is based on the width of the train and its dynamic envelope. Additionally, a 2- to 4-ft-clear width may be required for the emergency walkway, either between the tracks or on the outside of the tracks as shown in Figure 8.1-2. The location of the walkway is dependent on the center or side station platform. The preliminary planning criteria for wayside APM guideway are provided in Table 8.1-1.

Within the wayside there may be need for failure management crossovers to support the high level of reliability needed for APM systems. These failure management crossovers are typically placed approximately 1,000–1,500 ft from the station. These locations should be identified during the planning and finalized during system design. Evacuating from APM vehicles in a switch area of the guideway is challenging. It should be noted that certain technologies require a minimum track spacing of about 22 ft on center for crossovers. Based on the candidate APM technologies, the planning should consider the best solution to provide the track separation for crossovers.



Source: Lea+Elliott, Inc.

Figure 8.1-2. Wayside guideway configuration.

Table 8.1-1. Preliminary planning criteria.

Description	Guideway Type		
	Station Area Guideway	Wayside Guideway	Crossover Area Guideway
Horizontal Curve			
Mainline	300 ft 150 ft$^{(1)(2)}$	300 ft 150 ft$^{(1)}$	Switch should be on tangent
Maintenance	150 ft	150 ft	None
Spiral	60-110 ft	60–110 ft	None
Superelevation	None	0%–6%	None
Vertical Curve and Profile			
Elevation	Station floor$^{(3)}$	$^{(3)}$	$^{(3)}$
Grade	0%	0%–6%	Constant
Transition – Vertical Curve	None	60$^{(4)}$–110 ft	None
Track Separation	Subject to station and crossover$^{(5)}$	15–16 ft	22 ft
Total Width of ROW	Subject to station and crossover	28–30 ft	35–40 ft
Preliminary Dynamic Width of Generic APM	12 ft$^{(5)}$	12 ft$^{(6)}$	12 ft$^{(6)}$

Source: Lea+Elliott, Inc.
Notes:
[1] Absolute minimum; impacts speed.
[2] Only at approaches.
[3] Elevation of vehicle floor must match station platform.
[4] Impacts APM speeds.
[5] For tangents.
[6] Technology dependent.

Crossover Area Guideway

Crossover tracks help provide APM system redundancy by allowing active trains to bypass a disabled train. The primary purpose of the guideway structure in this area is to provide support for mainline tracks, as shown in Figure 8.1-3.

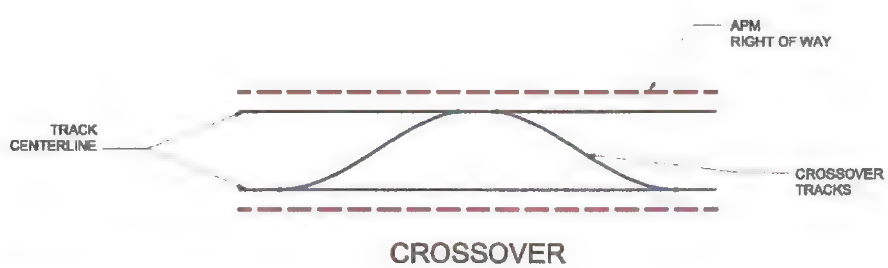
Preliminary planning criteria for APM guideways are provided in Table 8.1-1 for horizontal curves, vertical curves and profiles, track separation, width of right of way, and dynamic width of an APM train. Horizontal curve criteria are minimum values that correspond to APM speeds to ensure that the horizontal forces on passengers standing in the moving train are acceptable. The same is true for the vertical profile (grade) criteria, which are maximum values.

8.2 System Demand/Ridership Estimation

The estimation of ridership demand on a given APM alignment (with station locations) is typically the next step in APM planning. This section describes the different ridership estimation methodologies used at airports as well as important ridership estimate considerations.

There are two common APM ridership methodologies, best described as top-down and bottom-up.

1. The top-down ridership methodology takes an airport's annual passenger numbers for the design year and applies



Source: Lea+Elliott, Inc.

Figure 8.1-3. Crossover guideway configuration.

successive factors to determine a peak-hour, peak-direction APM passenger volume for the design hour.
2. A more detailed, bottom-up approach takes a gated flight schedule for the design day and combines aircraft board/deboard rates, walk distances, walk speeds, flight crew factors, airport employee factors, and so on, to determine system ridership throughout the design day. This methodology typically uses simulation software and gives results at a greater level of detail.

Deciding which of the two ridership methodologies to use is a function of the level of planning and of the data available to the planners. The two different estimating methodologies are described in the following subsections.

8.2.1 Top-Down APM Ridership Estimation

As with other planning methodologies, the top-down APM ridership methodology has inputs, analysis, and outputs. The inputs required to perform a top-down estimate vary between airside APM systems and landside APM systems.

For an airside APM system, inputs include: (1) the relevant design year activity level (MAP) for the airport, (2) peak month factors, (3) average day of the peak month factors, (4) hourly factors for air passenger arrivals and departures by concourse or terminal, (5) hourly surge factors, (6) passenger baggage characteristics, (7) passenger origin/destination percentages, (8) airline flight crew percentages, and (9) airport airside employee populations and shift times. The application of these factors and percentages to the annual passenger activity data results in surged hourly flow rates of airside APM riders for the peak hour of the design day, which is the common APM ridership metric for sizing the APM fleet. A surged hourly flow rate is the peak demand within a portion of the peak hour, which is then converted into an hourly equivalent number. This accounts for surges within the hour. For example, a 50% surge factor represents half of the hourly demand occurring in the peak 20 minutes. A ridership methodology graphic is provided in Figure 8.2.1-1.

The surged hourly design volumes of potential APM riders must be considered within the airside configuration context of the airport to determine the number of passengers who would ride the APM system. For example, passengers traveling between separate buildings (e.g., the main terminal and a remote concourse or terminal) would presumably all ride the APM. Exceptions to this would be airports with other conveyance options, such as underground walkways or buses where the APM may only accommodate a percentage of total inter-terminal passenger traffic.

For airports with central processing functions (check-in, baggage claim, etc.) and all airline gates within a single terminal, an APM would typically only accommodate passengers whose intra-terminal trip exceeds some walk distance or travel time threshold. These level-of-service indicators can vary by airport and are influenced by the passenger type (business traveler, vacation travelers, etc.) and overall airport configuration and goals.

Outputs for this airside ridership analysis are the surged hourly ridership volumes in each direction between all station pairs and to/from (on/off) volumes for each APM station. The peak station-to-station ridership volume then becomes an input into sizing the peak period train length (thus station length) and operating fleet. The peak period station on/off volumes become inputs into the station sizing process, in terms of platform length and width (to accommodate circulation and queuing areas) as well as the vertical circulation elements (escalators, elevators, and stairs).

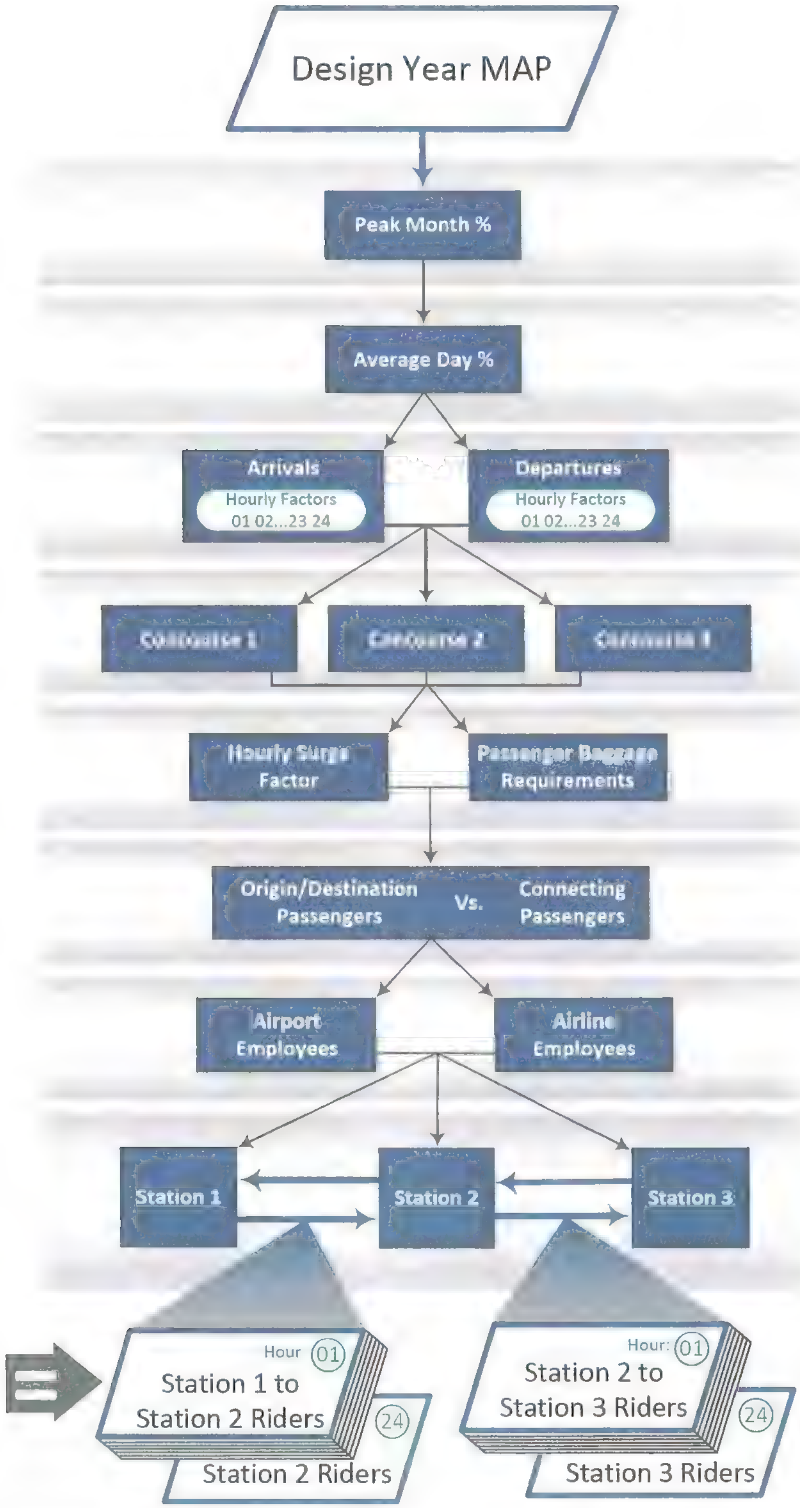
For a landside APM system, the top-down ridership estimation inputs include many of the same inputs as airside estimation. Other inputs unique to a landside estimate include airport access mode share for both passengers and employees, passenger party size, and passenger arrival patterns to the airport by flight type (domestic or international). The application of these landside factors to the annual activity level is the process that results in bidirectional hourly surged volumes of landside APM riders. This output is then used as an input to a subsequent APM fleet sizing analysis.

As with the airside data, the hourly volumes of landside APM riders must be considered within the landside environment of the airport for the design year. Landside environment components to be considered include: (1) the location and size of airport parking (passenger short-term and long-term, as well as employees); (2) the presence and location of a regional rail or other transit transfer station(s); (3) rental car lots; (4) the roadway network; (5) other facilities that influence the potential location of an APM alignment; and (6) the location, capacity, and frequency of other landside conveyance options such as walking, moving walks, and on-airport circulator buses.

Similar to the airside ridership analysis, outputs are the surged hourly station-to-station directional flows and the individual station on/off volumes. These outputs become inputs to the subsequent train length, fleet sizing, and station sizing analyses.

8.2.2 Bottom-up Ridership Estimation

The bottom-up (or flight schedule) APM ridership methodology is more typically applied for airside APM ridership estimates than for landside estimation. The key input is the gated flight schedule for the future design day. This schedule provides aircraft arrivals and departures throughout the day by airline, flight type, and gate. Information included in such a schedule includes the time of the flight, type of aircraft, aircraft seats, load factor, and origin/destination factor. With



Source: Lea+Elliott, Inc.

Figure 8.2.1-1. Airside APM—top-down ridership methodology.

this more-detailed information, passenger volumes to and from airside APM stations can be determined at the minute-by-minute time increment as opposed to the 15- to 20-minute (surged hourly) basis of the top-down ridership approach.

To obtain accurate passenger flows at a minute-by-minute level, additional factors are applied to the flight schedule ridership analysis, including passenger deboarding rates by aircraft type, passenger walk speeds, gate-to-station distances, terminal corridor flow capacities, and vertical circulation capacities accessing the APM station platform.

Passenger flow analysis at this level of detail is typically performed with simulation software by specialized professionals. Such analysis is carried forward to determine the required number of station vertical circulation elements and the platform length and width dimensions. The methodology for passenger flows at stations is provided in Section 8.4.2. The APM station on/off volumes are combined to determine APM system station-to-station ridership volumes. These volumes are in turn used in the APM fleet sizing analysis.

8.3 System Capacity and Fleet Sizing

The ridership demand estimates developed above should then be applied to the alternative system configurations to calculate the required APM system capacity. This is usually expressed as passengers per hour per direction. This calculation is a crucial aspect of the overall planning process since it will dictate the physical and performance characteristics of the APM and greatly influenced the APM's capital cost.

Passenger comfort and convenience is the focus of much of the analysis, which includes considerations such as:

- **Area per passenger**—Passenger comfort and personal space requirements are a major consideration in determining the appropriate area-per-passenger allocations. For example, in an airside airport setting with many connecting business travelers familiar with an APM system, a smaller area-per-passenger allocation may be acceptable. Conversely, in a landside airport setting with many leisure travelers that are less familiar with transit, a larger passenger area allocation is appropriate. Due to the variation in specific baggage profiles at different airports, it is recommended that a baggage survey be performed and the results compared with similar airports that currently have an operating APM.
- **Number of seated passengers**—The appropriate number of seats on a train depends on the duration of the trip: the longer the trip the more seats are required for passenger comfort. For many airside APMs, the total APM travel time is very short and there are no seats within the vehicle. Other factors, such as the type of riders, can influence how many passengers will require seats. For example, if there are a large number of elderly passengers in a particular airport market, there could be a desire by the airport to provide more seats.
- **Accommodations for passengers in wheelchairs and passengers with strollers**—The area allocation for passengers with wheelchairs is a consideration in determining overall spatial requirements. Also, a larger space allocation for passengers with small children should be considered given the use of strollers.
- **Accommodations for baggage**—Airside and landside APM systems have different space requirements for baggage given that airside APM systems must only accommodate carry-on baggage and landside APMs typically accommodate all of a passenger's baggage. Thus a very important aspect of determining system capacity is the analysis of riders' baggage. Space requirements (and therefore system capacity) for different types of APM passengers can vary widely because of the baggage they carry. Baggage requirements typically involve consideration of baggage to be checked, baggage to be hand carried, and baggage carts.

  Depending on the proposed APM application, one or more, perhaps even all, of the above items must be considered. For a proposed landside APM, passengers may be carrying both baggage to be checked and hand-carried baggage, perhaps on a baggage cart. For airside APMs, only hand-carried baggage need be considered; however, carts (possibly smaller ones) may still be allowed, depending on the airport policy. International passengers typically have more baggage and require more space than domestic passengers. Employees and visitors typically have little or no baggage and will therefore require less space than passengers.

  Analysis of baggage issues involves applying of historical data regarding the amount of baggage that typically accompanies each class of passenger. These data are constantly changing, with changes in demographics, bag technology (e.g., advent of roller bags), and airport baggage screening requirements. Surveys to establish baggage characteristics in a specific market may also be useful in establishing the baggage requirements.
- **Accommodations for baggage carts**—Landside APM systems are sometimes planned to allow baggage carts on the trains to enhance passenger service, minimize the effort required to move baggage, and expedite boarding and deboarding times. A baggage survey can help to define the percentage of passenger's with baggage carts in a given market so that accurate space allocations can be established.

8.3.1 APM Vehicle Characteristics

APM vehicles are fully automated, driverless, typically either self propelled or cable propelled, reliable, and provide a high degree of passenger comfort and safety. Vehicle speed, capacity, and maximum train length are dependent upon the

type of technology selected. The majority of APM vehicles have capacities of 50–75 passengers at airports, depending on their baggage characteristics. The original landside Newark AirTrain had smaller vehicles/cars with a six-car train holding about 70 passengers. At the other end of the spectrum, the airside Atlanta APM's four-car trains hold up to 300 passengers.

Photo: www.bombardier.com

Newark AirTrain

Self-propelled APM vehicles are electrically powered by either AC or DC provided by a power distribution subsystem. Vehicle propulsion may be provided by DC rotary motors, AC rotary motors, or AC linear induction motors. Rotary motors transmit thrust through a shaft/gearbox/wheel arrangement. With LIM, the motor's stator is installed on the vehicle and the rotor is installed on the guideway. Thrust is transmitted through the air gap by magnetic flux produced by three-phase currents.

Cable-propelled vehicles are also electrically powered but are pulled by an attached cable that is powered by a fixed motor drive unit located along the APM alignment, typically at one end of the guideway. Cable-propelled vehicle power (lights, electronics, HVAC, etc.) is typically provided via a 480 volt AC wayside power rail system.

The typical airport APM single vehicle is approximately 40-ft long and 10-ft wide and can be coupled into trains as long as four vehicles. The maximum train length can potentially be increased beyond four vehicles but would require some significant vehicle redesign and has not been undertaken to date. A single vehicle has typically held about 50 passengers landside and 75 passengers airside due to the different baggage characteristics. Somewhat higher passenger capacities are being seen in other parts of the world with different baggage levels and different passenger crowding levels.

APM vehicles are typically equipped with a thermostatically controlled ventilation and air conditioning system, automatically controlled passenger doors, a public address

Photo: www.bombardier.com

Two-Car APM Shuttle

subsystem, passenger intercom devices, a pre-programmed audio and video message display unit, fire detection and suppression equipment, seats, and passenger handholds. Some APM vehicles are designed to accommodate baggage (baggage racks) and baggage carts (stronger interior walls).

APM vehicles can be supported by rubber tires, steel wheels, air levitation, or magnetic levitation. A detailed description of each type of APM vehicle suspension follows:

Rubber tires—APMs using a rubber-tire suspension bogie also use concrete or steel guidance structures. A special coating is used on elevated structures to provide adequate traction without abrasion to the tires. The running surfaces are attached to a primary surface (typically concrete or sometimes steel) in a manner that maintains proper alignment. When climate conditions require, heating (by

Photo: www.bombardier.com

Rubber-Tire APM Vehicle

electric resistance wires or pipes with heated solutions in the running surface) might be provided for the running tracks on sections of the guideway exposed to the elements to aid in maintaining good tire adhesion in the event of snow or ice.

Steel wheels—Some APM vehicle types use steel-wheel bogie suspension. The primary advantages of steel wheels on rail tracks are simple vehicle guidance, low rolling resistance, and fast and reliable switching. Rail tracks, whether tunnel, at grade, or elevated, are typically directly fixed to concrete cross ties. Guideway heating is not required for steel wheel/rail systems.

Photo: www.bombardier.com

Steel-Wheel APM Train

Air levitated—Air-levitated APM vehicles ride on a cushion of air, rather than wheels, allowing them to travel quietly and without friction on the running surface. The vehicle and the concrete guideway "flying" surface are separated by an air gap that is between ⅛ in. and ¼ in. Low-pressure air flows from blowers in the vehicle chassis to air pads. Special surface finishing requirements are needed to sustain the surface texture since any unusual roughness, or elevated expansion joint covers, can contribute to rapid wearing of the pads.

Photo: Otis Elevator

Air-Levitated APM Vehicle

Magnetic levitation—Maglev vehicles are magnetically levitated and propelled by linear motors (either induction or synchronous). Electromagnetic maglev systems use permanent magnets or electromagnets and have a relatively small (less than one in.) gap between the vehicle and the running surface. Electrodynamic maglev systems develop their levitation using a moving magnetic field. There are high-speed (200+ mph) and low-speed (30–60 mph) maglev systems, but only low-speed maglev is applicable to airport APM implementations. There are no currently operating airport Maglev systems. The initial Birmingham (UK) Airport landside APM was a maglev system.

Photo: Lea+Elliott, Inc.

Maglev APM Train

Vehicle steering and guidance mechanisms vary by technology. In general, steering inputs are provided to vehicle bogies through lateral guidance wheels or similar devices that travel in continuous contact with guideway-mounted guide beams or rails. The steering inputs cause the bogies, usually located at both ends of each vehicle, to rotate so that vehicle tires do not "scrub" as they move through horizontal curves. Center and side guidance mechanisms are used by different manufacturers, and each type has unique characteristics. Descriptions of each type of vehicle guidance are provided below.

Side guidance is generally provided by structural steel or concrete elements located along both sides of each guideway lane. Wheels roll along the contact face of the side guidebeams/rails so that vehicles are held between the side guidebeams/rails. The side guidebeams/rails may be located outside the main wheel paths and can be located either above or below the top of the primary running surface. Alternately, they can be located between the main wheel paths, in which case they are generally located below the top of primary running surfaces. Side guidance generally requires special mechanisms and trackwork to maintain positive guidance through merge

and diverge areas (switches). These mechanisms differ considerably among APM technologies.

Photo: Lea+Elliott, Inc.

Side Guidance

Central guidance systems generally use a structural steel guidebeam along the guideway centerline to provide guidance and steering inputs. Guide wheel configurations and materials differ by technology, but generally roll along both sides of the center guidebeam, trapping the beam between the guide wheels. Central guidebeams are located at various elevations relative to the top of primary running surfaces, dependent upon APM technology. Because the vehicle's primary running wheels must roll across a guideway centerline through merge and diverge areas (switches), special movable replacement beam type switches are usually employed. These types of switches replace a straight guidebeam with a curved turnout guidebeam and vice versa depending on the vehicle's travel direction.

Photo: Lea+Elliott, Inc.

Central Guidance

8.3.2 APM System Capacity Methodology

System capacity refers to the number of passengers transported by the APM in one direction per unit of time (usually an hour). It is a dynamic capacity of passengers over time as opposed to a static capacity, such as a vehicle capacity of 75 passengers. The usual system capacity metric used during the planning stage of the project is passengers per hour per direction. The appropriateness of this metric for planning purposes is discussed in the ridership section (Section 8.2) of this guidebook.

For a typical airport APM planning exercise, a number of APM planning aspects will already have been developed by the time that system capacity is to be determined. These include system ridership, alignment, station locations, and end-station geometry.

During the planning stage of a project, system capacity is typically determined for a generic APM technology by using the following steps:

1. Determine round trip time for single train. This is usually determined by simulation, using alignment characteristics and technology-generic train performance.
2. Determine the capacity (passengers per vehicle) of a single-vehicle train given the airport's passenger/baggage profile. This can vary greatly between airside and landside applications. Typical airside floor space per passenger with only carry-on baggage is 4–5 sq ft per passenger. For landside, passengers with all baggage, the floor space is 5–7 sq ft per passenger. Seated passengers take about the same floor space, while passengers using baggage carts can take up to two times that space. Due to the variation in specific airport baggage profiles, it is recommended that a baggage survey be performed and the results be compared with similar airports with existing APMs.
3. Determine the system capacity of a single-vehicle train in terms of passengers per hour per direction. The system capacity of a single-vehicle train is the number of trains per hour past any given point times the vehicle capacity determined in step 2. The number of trains per hour is the headway in seconds (for one train, this is the round-trip time from step 1) divided into 3,600 seconds per hour.
4. Determine the minimum headway (maximum number of trains) that can be achieved for the given alignment. The minimum headway varies by system configuration. For a single-lane shuttle, it is the round trip time. For a dual-lane shuttle, it is half of the round trip time. For a pinched-loop configuration, the minimum headway is determined by throughput of the end stations' switch configurations (obtained from train simulation modeling), station spacing and train control protocol, station dwell times (a function of the number of doors, passenger volumes, and boarding/alighting rates), and other factors. For pinched-loop system

planning purposes, usually a minimum headway is limited to about 90 seconds. Shorter headways might be possible for some technologies and configurations, but being too optimistic could have negative consequences if subsequent technology selection and operations prove not to meet this standard.

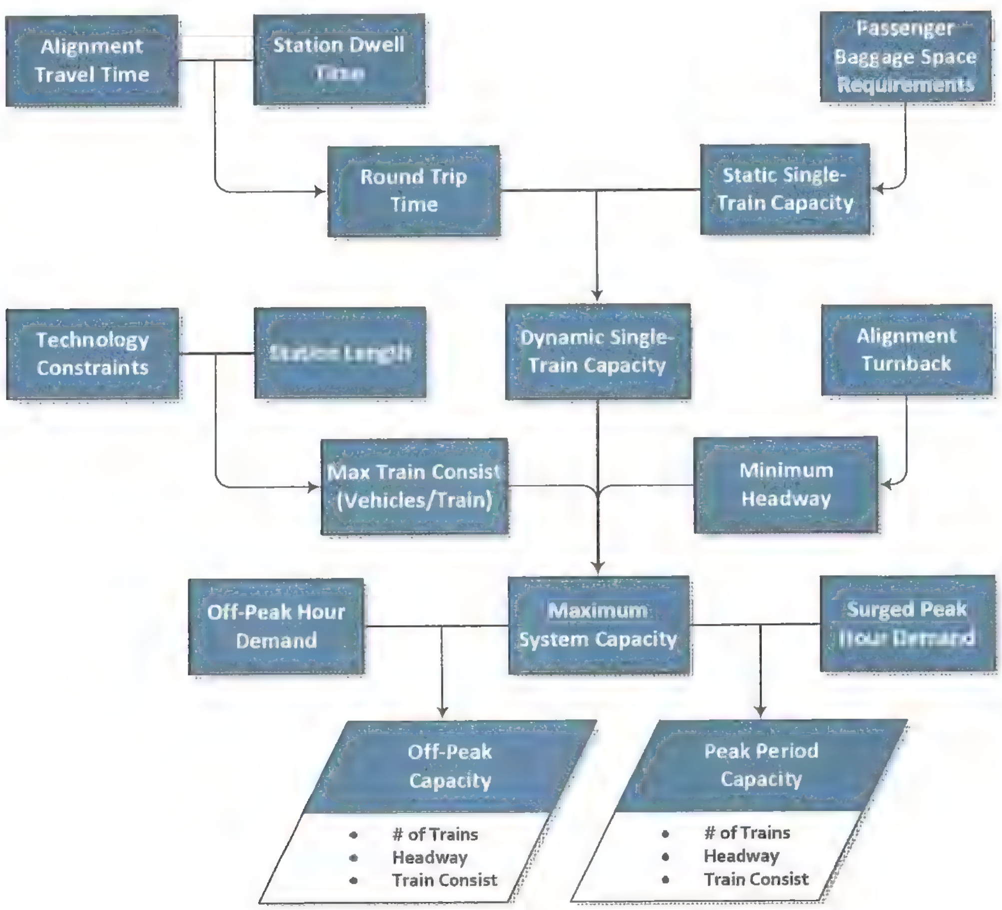
5. Determine the maximum train length (cars per train) given technology constraints or station length constraints. The maximum train length for most APM technologies is about 170 ft (four 42-ft cars) although some APMs have up to six similarly sized cars. Some system configuration and station locations might constrain this length. The maximum train length and minimum headway determine the maximum capacity of a given system.
6. Iterate between number of trains and train length to generate sufficient hourly capacity compared to the surged peak hour demand. A major advantage of automated systems is the greater frequency of trains, which equates to a better level of service. Given the cost of stations, it is often preferable to have shorter headways, shorter trains, and therefore shorter/smaller stations. Thus, more frequent, shorter trains usually are preferred to less frequent, larger ones. Typically one plans for approximately two-minute headways and adjusts the number of cars per train accordingly.

The APM capacity estimation methodology is shown in diagrammatic form in Figure 8.3.2-1.

8.3.3 Planning Criteria for APM Trains

APM trains are sized based on the estimated number of passengers (ridership demand analysis), the passenger characteristics, and the physical and operational characteristics of the expected technology/technologies. Train sizing involves a number of criteria, including:

Vehicle length—The most common APM vehicles that have been implemented at airports can be referred to as large APM vehicles of approximately 40 ft in length and 10 ft in width. Most current APM suppliers offer self-propelled vehicles of this length. Examples are Bombardier, IHI, Mitsubishi, and Siemens (formerly Matra). Some self-propelled and cable-propelled APM suppliers offer vehicles of shorter length, including those of Schwager Davis,



Source: Lea+Elliott, Inc.

Figure 8.3.2-1. APM planning capacity methodology.

Inc., Doppelmayr Cable Car (DCC), and Leitner-Poma Mini Metro. Bombardier's vehicle at New York–JFK is the lone example of a larger (and faster) vehicle for that airport landside application and is substantially longer (total distance and station spacing) than other airport APMs.

Maximum train length—As a practical planning guide, large self-propelled trains can be as many as six vehicles, approximately 240-ft long. In pinched-loop systems, the maximum train length is limited by vehicle structural limits and station platform design requirements, resulting in a typical maximum length of a 4-vehicle train of approximately 160 to 170 ft. Cable-propelled trains are typically limited by bullwheel friction, cable length, grade, curvature, and other factors. Wide vehicles (10 ft or greater) are typically limited to about 120 ft in length. With some technologies, the individual vehicles that make up a complete train can all be operated as individual units (single vehicles). Other technologies have two or more vehicles permanently coupled.

Train sizing—Planning criteria for train sizing includes (a) number of passengers (seated and standing), (b) passenger type and characteristics (secure, nonsecure, bags, etc.), (c) space implication of carry-on bags and/or luggage, and (d) vehicle design implications of any baggage carts. Additionally, passenger boarding and deboarding requirements affect train sizing, with consideration of the number of vehicle doors, door width, platforms on one or both sides of the train, and the effect of any interference from train door openings and columns/structures in the station. For this reason, the side-center-side or triple-platform configuration can allow a system to have shorter or fewer trains due to its shorter dwell times.

Train sizing is typically iterative with respect to trade-offs for train length, headway, station platform sizing, and vertical flow requirements in the stations. Certain APM suppliers provide married-pair vehicles, requiring train lengths in increments of two vehicles. Some types of monorail vehicles have barriers between cabins, which can reduce the deboarding rate for the affected cabin in the case of door-set failures. Some train technologies have walk-through capacity, which helps to equalize the passenger distribution throughout the train.

Train performance—Depending on the maximum distance between stations, the maximum train speed can be an important factor in train performance and other design considerations. Typical APM systems have maximum train speeds between 32 and 40 mph, but vehicle designs can be specified for speeds of 50 mph. A greater specified train speed may limit the number of compliant vehicle designs. The lateral forces on standing passengers during acceleration, deceleration, or going through curves can result in the need for speed restrictions so as to provide adequate ride quality.

Headway and line capacity—Train headway is typically limited by the time needed to reverse trains at the end stations. The ability to reverse trains onto the opposite track beyond the end-of-line stations minimizes the headway, but increases the round trip time and the resultant fleet size. It also increases the length (and cost) of the system. The ability to crossover before the station platform and perform turnbacks at the station can reduce the fleet size, but also increases the operating headway. Line capacity should be variable by changing operating fleet (headway) size a few times per day to meet variable ridership demand. This can save fleet-vehicle miles and operating costs. Ridership forecasts need to be determined with high confidence levels when line capacity is varied over the day.

Fleet size—The fleet size for a pinched-loop system is typically a function of the maximum operating fleet during the peak period, plus one full-length standby train and a sufficient number of spare vehicles to accommodate periodic vehicle maintenance activities and unexpected repair activities. Typically, the number of spare vehicles should be about 20% of the operating fleet (typically at least two spare vehicles). The number of spare vehicles can be increased to limit the number of operating shifts required for an APM system. Periodic maintenance must typically be performed during the night shift due to the number of spare vehicles. With additional vehicles, it can be possible to perform all of the maintenance activities during the morning and afternoon shifts, thereby eliminating a third shift of maintenance personnel and eliminating the wage increase necessitated by third-shift personnel.

Provisions for disabled and mobility-impaired passengers—The Americans with Disabilities Act (ADA) requires that vehicles, like stations, must accommodate persons with disabilities. Requirements include:

- Horizontal door gaps,
- Vertical door gaps,
- Door widths,
- Vehicle seating and signage,
- Vehicle handrails and stanchions,
- Vehicle flooring,
- Vehicle public address system, and
- Vehicle accessibility signage.

8.3.4 Planning Criteria for System Redundancy

Reliability and system availability are of paramount performance to APM success. Accordingly, a professional evaluation must be made to assess various predictable failure modes and develop designs and/or failure operating modes to deal with each. Solutions may include redundant physical features such as crossover switches and sidings, special operating modes

(e.g. a series of station-to-station shuttles to operate around a blocked link), and other approaches. Many of these will include additional costs.

Redundancy refers to the methods by which an APM system can overcome a vehicle or wayside failure and maintain passenger service, albeit often at a lesser level of service to the passenger. The methods to achieve redundancy vary greatly, as do the costs and necessity of such methods. The costs of achieving redundancy should be weighed against the necessity for, and the level of, redundancy. For example, an APM system that offers the only efficient means of accessing a remote concourse of an airport should typically have a high level of redundancy because a failure of the APM would have a catastrophic negative effect on airline operations. Conversely, an APM system flanked by a pedestrian corridor with associated moving walkways would have lesser needs for redundancy because the APM's operation would not be essential to airline operations. Typically, airside APM systems at large hub airports have greater redundancy than landside APM systems due to the time-critical nature of the gate-to-gate connections of airline passengers.

APM system redundancy can be achieved in a variety of ways. The cost of implementing the methods of redundancy versus their value should be carefully considered by the airport from the APM's planning phase onward. The following are three ways in which redundancy can be achieved:

Initial design decisions—Redundancy is sometimes inherent in the design of the APM system. Thus, initial design decisions can greatly affect redundancy. For example, both trains of a cable-propelled dual-lane shuttle APM system can be attached to a single cable and powered by a single motor. This would be an economical design decision. However, this system would have very poor redundancy because a failure of the motor or a failure of a single sheave supporting the cable would shut down the entire APM system. An alternate design decision would be to power each train (and guideway lane) of the dual-lane shuttle independently, with separate motors and cables. Thus, a single-point failure would shut down only a single lane and the APM system would retain 50% of its service capacity until repairs could be made. However, this is a more expensive design solution.

Alternate routes—The physical layout of the APM system's guideway often allows alternate routes to be run during a vehicle or wayside failure. For example, a one-way loop system can revert to a shuttle route, or a system of shuttle routes, in the event of a single-point or multi-point failure. Likewise, a pinched-loop system can contain a variety of shuttle routes whereby trains can continue to operate in the event of vehicle or wayside failure.

Run-around modes—Run-around modes typically encompass alternate routes made possible by guideway switches and/or a system of switches constituting crossover(s). In this case, the trains can be programmed to literally run around the failure point(s) by being routed through switches onto alternate sections of guideway.

8.4 Stations

A successful APM system must be well integrated into the airport and terminal facilities. This allows the most efficient system operation and the easiest use by passengers. Stations are located along the guideway to provide passenger access to the APM system. Stations for airport APMs are typically online, with all trains stopping at all stations. The station equipment provided by the APM system supplier includes automatic station platform doors and dynamic passenger information signs. The stations typically have station APM equipment rooms to house command, control, and communications equipment and other APM equipment. This section covers APM station characteristics, components, and the methodology employed in planning for an APM station.

8.4.1 APM Station Characteristics and Components

An APM station provides the physical connection between the APM train and the airport facilities it serves. An APM station comprises one or more platforms to facilitate passenger boarding and alighting APM trains. Typically, platform edge walls provide a barrier between the platform and the guideway to help ensure the safety of passengers as trains arrive and depart the station. Doors are provided in the platform edge wall to enable the direct interface between the trains and the platform. Passengers may access the station directly from the adjacent facility if it is on the same level, or may use vertical circulation to access the station either from a level above or below the APM platform level.

The APM station plays a critical role in the effective operation of the APM system. As the direct interface between the APM and the airport facilities, the station must be appropriately sized, configured, and equipped to accommodate the flow of passengers effectively and efficiently. Thus, considerations such as passenger separation requirements, passenger baggage characteristics, vertical circulation requirements, and queuing areas must be taken into account when planning an APM station. This section addresses the most critical elements affecting APM station planning. These elements include:

- Platform configuration,
- Vertical circulation at the station, and
- Station doors.

Platform Configuration

The barrier walls, door sets, and passenger queuing area within an APM station are called the platform. A single APM station may have multiple platforms. Chapter 4 introduced three APM station platform configurations: side, center, and triple (flow through). For reference, these three configurations are presented diagrammatically below in Figure 8.4.1-1.

The type of platform configuration used depends upon many factors that can vary widely among airport applications. These factors include:

- Passenger separation requirements,
- Passenger demand at the station,
- Physical constraints of existing facilities that limit the type of station that can be implemented, and
- Level change requirements.

Passenger Separation Requirements

Passenger types for airport APM systems include origination and destination passengers, transfer, secure, non-secure, sterile, and non-sterile. In some APM systems, O&D passengers are separated for security and sterility reasons. For example, at an international airport, originating passengers who are departing the country are either residents or visitors who have been granted permission to be in the country through the immigration service. Arriving destination passengers have not yet been cleared by the immigration service to enter the country. For this reason, these passenger types will be separated. The APM and the station platforms must accommodate this type of separation requirement.

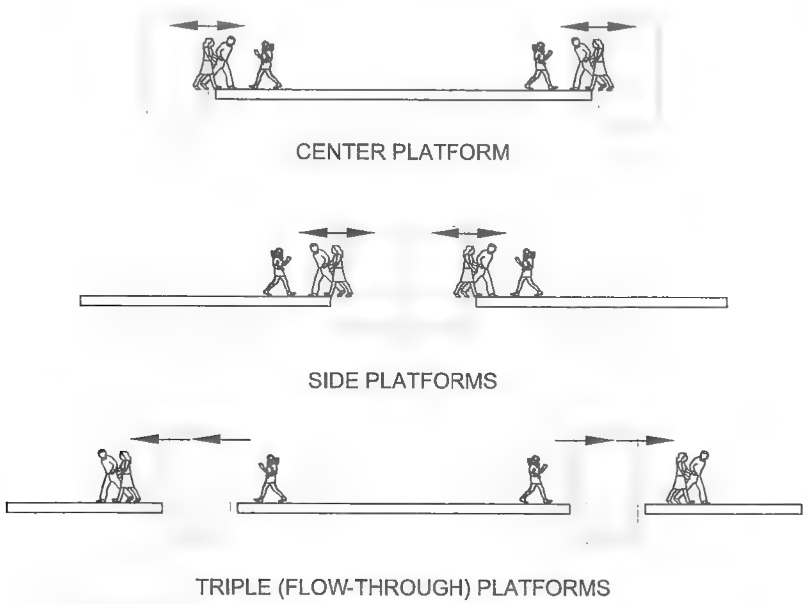
The best approach to maintaining passenger separation is to provide separate platforms for each passenger type. Otherwise, platform partitions are required to separate passengers by type on the same platform. For example, a center platform without partitions could not provide for the separation of passengers unless separate APM systems were provided for each passenger type. A partition would be required on a center platform to maintain passenger separation. This would also require separate vertical circulation cores for each passenger type. These requirements lead to increased platform size and greater vertical circulation requirements, thereby increasing station cost.

Separation may be more effectively handled with side- or triple-platform configurations. In these cases, separate platforms can be provided to each passenger type to maintain separation. Partitions and separate vertical circulation cores on each platform are not necessary, thereby possibly reducing overall platform size and vertical circulation requirements.

Passenger Demand

The anticipated passenger demand at each station will influence the size and possibly the type of platform configuration. For example, a double side platform configuration may be appropriate if the total anticipated demand of both directions of travel is high and expected to grow over time. Congestion on platforms can be mitigated by providing a separate platform to each direction of travel.

The triple platform configuration allows the most efficient movement of passengers in high-demand situations.



Source: Lea+Elliott, Inc,

Figure 8.4.1-1. Profile views of platform configurations.

The flow-through movement that it provides permits the deboarding passenger unobstructed access for alighting the trains while affording boarding passengers the same unobstructed access. Boarding and deboarding passengers are not required to use the same doors and platform spaces. This helps improve passenger flow and reduce train dwell times. Where level changes are required to access the adjacent facility, this platform configuration requires fewer vertical circulation elements as each platform requires only up or down escalators, not both.

Level Change Requirements

The need for level changes, or lack thereof, should be considered in the planning of the platform configuration. The appropriate selection of the platform configuration could reduce or eliminate the need for vertical circulation, thereby reducing the station size, when the level of the adjacent facilities is considered.

APM platforms that are on the same level as the adjacent facilities might be configured such that no vertical circulation is necessary. Examples of APM station platforms not requiring vertical circulation elements include the dual-lane shuttle APMs at Tampa International Airport and Orlando International Airport.

An end station that is on the same level as the adjacent facility would not require vertical circulation. In this case, the station acts as an extension of the facility, allowing passengers to walk directly between the facility and platforms, regardless of the platform configuration applied. See Figure 8.4.1-2 for an illustration of an end station that does not require a level change from the APM station.

APM stations on the same level as the adjacent facility that are not end-of-line stations require vertical circulation if the configuration has a center platform. This would be the case for a center platform and a triple platform configuration. The vertical circulation is needed to transfer passengers up and over (or down and under) the APM guideway. This requirement for vertical circulation increases the size and cost of the station.

On the other hand, a side platform may not require vertical circulation in the station if passengers are able to access the facility directly from the platforms and go in the desired direction. If the facility does not provide equivalent service to both sides of the platform, then vertical circulation would be required, either on the platform or within the facility. Either way, the vertical circulation is related to providing access to the APM and therefore should be considered as part of the total requirements of the APM system.

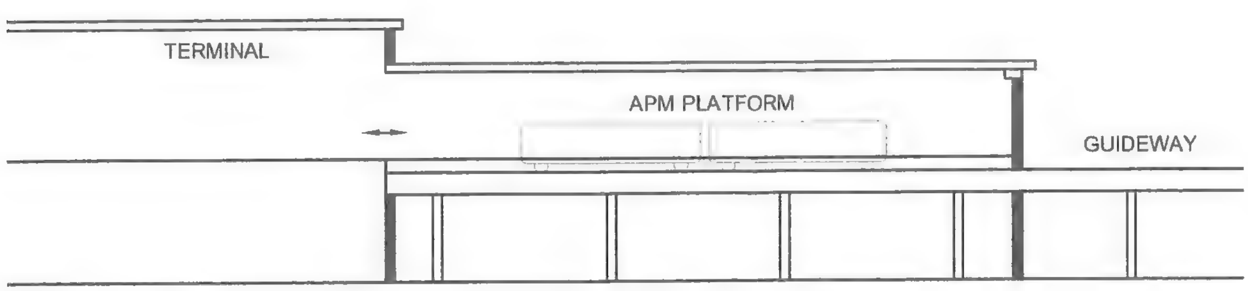
Physical and Geometric Constraints

Despite careful consideration of passenger separation requirements, anticipated passenger demand, and level changes, physical and geometric constraints within the airport facility can dictate the type of platform configuration. For example, consider a station planned to be constructed in a tunnel under an existing structure. The supporting structure beneath the facility may require that the guideways be widely spaced in this area. Consequently, a center or triple platform configuration may not be possible, despite being desirable in terms of other considerations such as passenger separation and anticipated demand.

Additionally, geometric constraints of the APM system may limit the available platform configurations. For example, dual APM guideways may not have the space to increase separation to serve a center platform, due to the geometric constraints of the APM system components. *ACRP Report 25: Airport Passenger Terminal Planning and Design* is an excellent reference for providing the context within which APM stations are located.

Station Doors

Physical and geometric constraints can preclude certain platform configurations. For this reason, the station interface between the APM and the adjacent facilities may not be the ideal solution, but one necessitated by the existing conditions. Additional consideration may be required in terms of station size, vertical circulation, and APM operation in these situations.



Source: Lea+Elliott, Inc.

Figure 8.4.1-2. Profile view of station requiring no vertical circulation.

Photo: Lea+Elliott, Inc.

Station Vehicle Door Interface

The station has doors that align with a stopped train, and the two-door systems work in tandem. The automatic station platform doors provide a barrier between the passengers and the trains operating on the guideway. These doors are integrated into a platform edge wall. Station doors at the vehicle entrance locations provide protection and insulation from the noise, heat, and exposed power sources of the guideway. The interface between the station platform and the APM guideway is also defined by the platform edge wall and automated station doors. This wall and door system is also designed to allow evacuation of the APM vehicles in the event of a misalignment of the vehicle with the station doors. This requirement is accommodated by either a castellated wall configuration or a straight wall with openable panels.

Dynamic passenger information signs are typically installed above the platform doors and/or suspended from the ceiling at the center of the station to assist passengers using the system. These dynamic signs provide information regarding train destinations, door status, and other operational information.

Vertical Circulation at the Station

Vertical circulation for APM stations, as well as throughout the airport terminals, is typically provided by escalators and elevators. The research produced from ACRP Project 03-14, "Airport Passenger Conveyance System Usage/Throughput," should be an excellent resource on these conveyance elements. The two vertical circulation elements are further described below.

- **Escalators**—Escalators are constant-speed passenger conveyance devices used to vertically transport people for relatively short distances along an inclined slope. They consist of separate aluminum or steel steps linked together in a manner that keeps the treads in a horizontal plane. Generally, escalator operation is continuous except for scheduled preventative maintenance or unplanned downtimes.

  Escalators can often be operated on either an on-call basis with push-buttons or with motion-sensors that detect approaching passengers and begin moving prior to their arrival. Nominal sizes for standard escalator step widths typically found at airports are provided in Table 8.4.1-1.

  Nominal speeds for standard escalators typically available on the market today are between 90 and 120 ft per minute. The primary standard for escalators in the United States is *ASME A17.1 Safety Code for Elevators and Escalators*, published by the American Society of Mechanical Engineers. In Europe, the primary standard is European Standard EN 115. There are some escalators that are specifically designed to accommodate baggage carts. Some airports allow passengers using specifically designed baggage carts to access the escalator.
- **Elevators**—There are two elevator types commonly used in passenger service: traction elevators and hydraulic elevators. Traction elevators use steel cables (or ropes) wrapped over a sheave to move the elevator cab up or down. The weight of the cab and people are counterbalanced with a counterweight, thereby requiring less energy to move the cab. This type of elevator gets its name from the traction generated by the friction between the steel cables and the sheave or pulley. Hydraulic elevators use hydraulic fluid to pressurize an

Table 8.4.1-1. Typical escalator characteristics.

Size	Nominal Width (in.)	Single-Step Capacity	Typical Applications
Medium	32	One passenger with one bag	Smaller airports
Large	40	Two passengers	Metro systems, larger airports, APM stations
Very Large	48	Two passengers plus	Newer large airports

Source: Lea+Elliott, Inc.

in-ground piston to raise or lower the elevator cab. Hydraulic elevators are typically only used for relatively short distances (6–7 stories maximum) due to the length required for the cylinder structure below. Hydraulic elevators are also slower than traction elevators.

Recent innovations in elevator system design include the use of microprocessor control systems, the use of permanent magnet motors with low-friction gearless construction, and machine-room-less elevators with the power units mounted between the elevator shaft wall surfaces and the guide rails.

Nominal cab sizes for standard commercial elevators vary considerably by manufacturer, elevator type, and model. A general range of sizes for passenger elevators used in airports today is as follows:

Small elevators: 5′8″ × 4′3″ with door width of 3′0″
Large elevators: 7′0″ × 7′0″ with door width of 4′0′

Consideration should be given to flow-through elevators for APM stations. These elevators have doors on both ends of the cab, allowing exiting passengers to use separate doors from entering passengers. This flow-through design allows more efficient boarding and deboarding of passengers, thereby reducing dwell times and possibly reducing the total number of elevators required. The primary standard for elevators in the United States is *ASME A17.1 Safety Code for Elevators and Escalators,* published by the American Society of Mechanical Engineers. In Europe, the primary standard is European Standard EN 115.

Many APM stations require vertical access because the APM train alignment is at a different vertical level than the pedestrian level of the facility being served by the APM. Vertical circulation to the platform can be at the ends or the center of the platform. The configurations with access at the ends of the platform are referred to as "single-ended" and "double-ended" if they provide access at one end or both ends, respectively. Figure 8.4.1-3 depicts a double-ended center platform station in plan view.

In some applications, vertical circulation is only provided at one end of a platform. This results in more congestion at that end of the platform. With all of the required vertical circulation elements at one end, the width requirement of those elements may increase the overall platform width. Figure 8.4.1-4 depicts a single-ended center platform station in plan view.

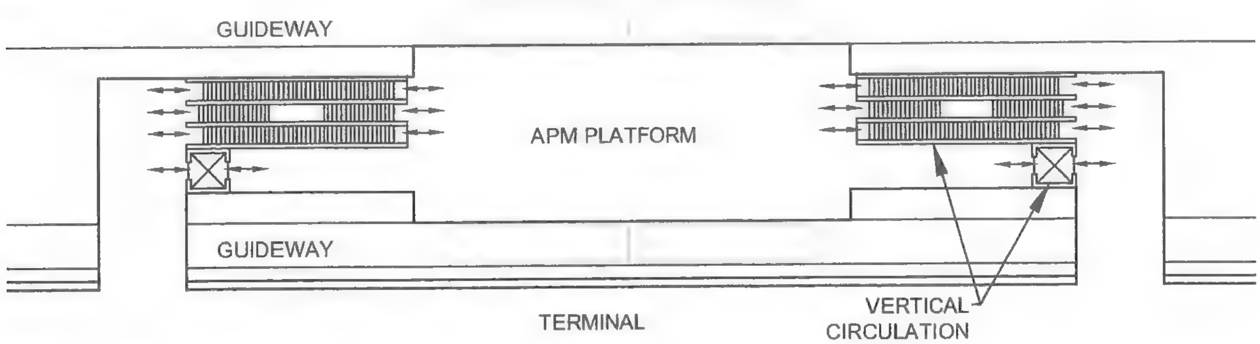
Figure 8.4.1-5 depicts two examples of a centrally located vertical circulation core on a center platform. The top example illustrates access from outside the central core, with the bottom example illustrating access from inside the central core.

Several factors determine where vertical circulation is located on the platforms, including the station orientation in relation to the adjacent facility, concentration of expected passenger demand, and physical and geometric constraints.

The orientation of the station relative to the adjacent facility influences the location of vertical circulation on the platform. Stations may be perpendicular or parallel to the adjacent facilities. Stations may also abut the adjacent facility or be located directly above or below it. The best location for the vertical circulation, in terms of station orientation, minimizes walk distances, queue sizes, and counterflows.

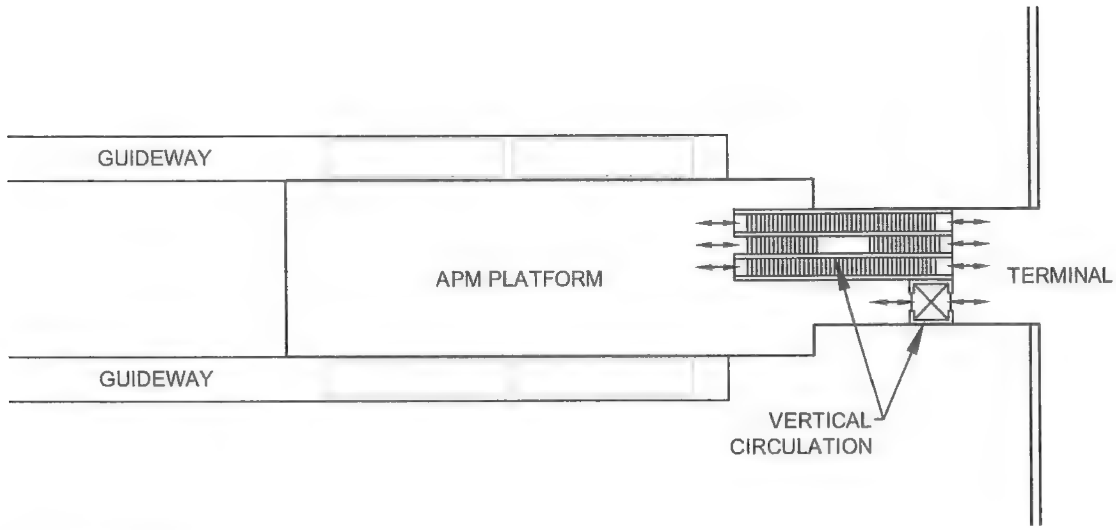
An APM station platform that is oriented parallel to a facility may be best served by double-ended vertical circulation. This configuration provides a better level of service since it distributes the passenger load between two vertical circulation cores, thereby reducing individual queue sizes, minimizing walk distance on the platform, and potentially reducing overall station width.

Conversely, for a situation where a station is oriented perpendicularly to a facility and abuts it at one end, vertical circulation may only be located at one end of the platform (see Figure 8.4.1-4) to minimize overall walk distance. Passengers exiting the station would not be required to walk in the opposite direction of the facility and then double back at the end of the escalator to proceed in their intended direction of travel. Single-ended platforms may result in increasing the overall width of the APM platform since all vertical circulation would be grouped together.



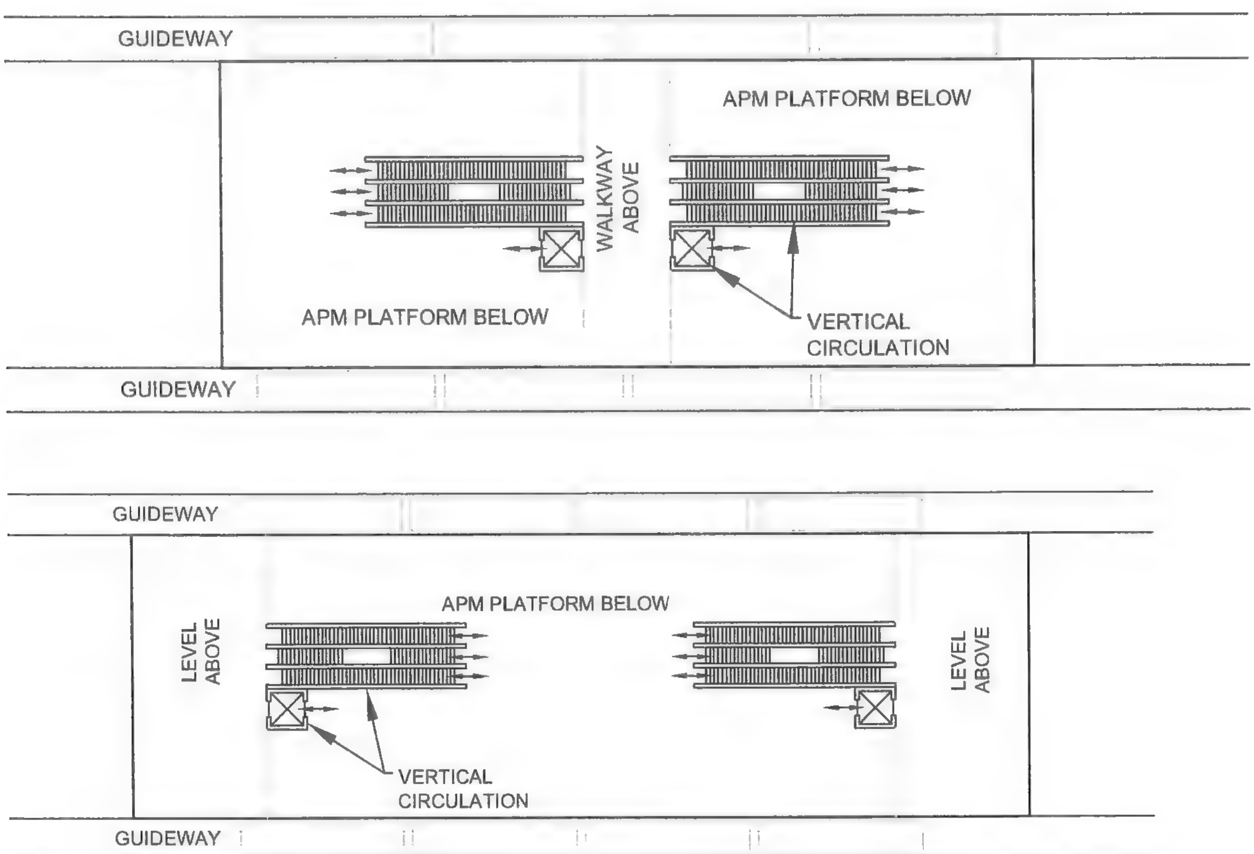
Source: Lea+Elliott, Inc.

Figure 8.4.1-3. Plan view of double-ended vertical circulation at a center platform station.



Source: Lea+Elliott, Inc.

Figure 8.4.1-4. Single-ended vertical circulation at a center platform station.



Source: Lea+Elliott, Inc.

Figure 8.4.1-5. Centrally located vertical circulation.

The concentration of passenger demand within a facility influences the location of vertical circulation on the platforms. Vertical circulation should, if possible, access the locations of the facility where passenger demand is concentrated. The passenger demand may be evenly distributed throughout the facility, or it may be concentrated at one end. Consideration should be given to the focus of the passenger demand when locating and sizing the vertical circulation access to the APM. For example, if the APM station is located directly beneath the baggage claim area, it may be more efficient to locate vertical circulation access at both ends of the baggage hall. This spreads passenger demand to both ends of the station, reducing congestion at the ends of the escalators and potentially reducing overall platform width.

Conversely, if the majority of passenger demand is focused at one end of a facility, it makes little sense to direct passengers away from that end. For example, if ticketing and check-in or baggage claim is located at one end of a facility, vertical circulation to the APM station should be at that end.

8.4.2 APM Station Planning Methodology

Planning of the location and layout of APM stations is based on: (1) the configuration and constraints of the terminal/airport, (2) minimizing passenger walk distances and level changes, (3) providing adequate circulation and queuing space to ensure passenger comfort, (4) promoting ease of use through wayfinding means, and (5) creating a safe environment. Many factors are considered in providing the optimal passenger experience with regard to these criteria, including:

Spatial accommodations—The size of the stations is based on the length of the trains, the number of passengers and their spatial requirements, the vertical circulation requirements, the passenger flows and circulation, and queuing requirements (at train doors and vertical circulation elements). Passenger comfort and safety are considerations in planning the appropriate size of a platform.

Minimize level changes—Level changes between passenger processing areas and APM station platforms should be minimized, if possible. In some cases, as with end stations, it might be possible to provide the platform at the same level as the activity center so that no level change is necessary.

Passenger boarding queues—Passengers form queues while waiting to board trains and to board vertical circulation elements such as escalators or elevators. It is important that these queues are separated so that other passengers can move around them freely. In addition, boarding queues should be fully dispersed among train operation doors so that passengers waiting for a train are not left behind on the platform. Vertical circulation elements should be sized, located, and of a sufficient number so that queues do not continually grow, creating a potentially unsafe situation.

Passenger flow analysis—The configuration of the platform layout should be planned to provide the best possible passenger flows. Cross flows of passengers can cause congestion, so space allocations should consider separating them. In some cases, it may be best to provide flow-through platform configurations such that passengers board from the center platform and deboard to side platforms.

Vertical circulation location—The location of the vertical circulation should be placed such that passenger movements are toward the passengers' destinations, necessitating no backtracking. Vertical circulation should be placed such that there is a visual connection for passengers deboarding the trains to aid in wayfinding and minimize confusion on the platform.

Vertical circulation analysis—Analysis of the number and size of vertical circulation elements provides for adequate service so that queues are not too long and the wait times in the queues are acceptable. When sizing the vertical circulation, such as the width of the escalators and the size of the elevator cabs, planners should consider passenger comfort, personal space requirements, and baggage space requirements.

Level boarding—The station platform and the vehicle floor should be at the same level, similar to an elevator, to meet ADA requirements. This provides for ease in boarding and deboarding and allows for passengers in wheelchairs, and with rolling baggage, baggage carts, or strollers, to board the vehicles with ease.

Station doors—Station walls and doors at the platform edge provide a separation between the platform waiting area and the APM guideway. This is for passenger safety and to keep objects, such as baggage and baggage carts, off the guideway. Station doors are especially useful in airports, where many passengers may not be familiar with using transit. Often airport APM stations are climate controlled, which is another reason that the walls and doors are needed.

Wayfinding—Passenger wayfinding aids make it easier for passengers to understand and navigate to their destination. While signage is important, it is also useful to provide for other visual cues to help assure the passenger that they are on the correct path. Creative measures can provide a subtle way of leading passengers to their destinations. An example of this is the use of art at Denver International Airport, where a series of tiny impressionist airplanes point toward the vertical circulation from the deboarding APM station platform. Other ways of accomplishing clarity in wayfinding include providing open vertical space that allows passengers to see the level

above or below the platform, which might be either the ticketing level of a terminal or the baggage claim level.

Perceived safety issues—Passenger's safety is a primary focus of planning APM stations. It is important to design stations that do not have hidden spaces that are obstructed from a passenger's view. As previously discussed, station platform doors and walls provide a safety barrier between the passengers and the trainway.

Passenger Space Allocations

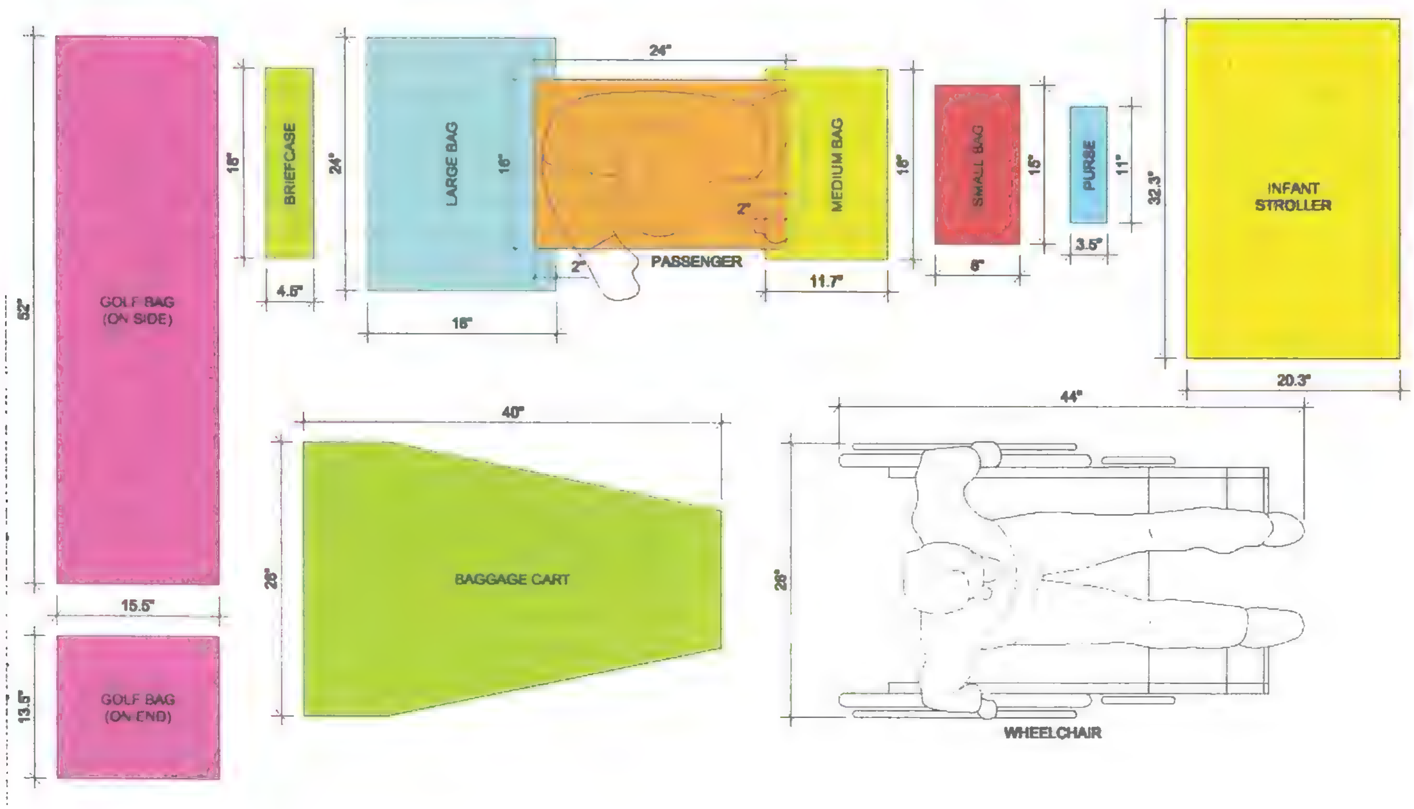
There is no such thing as an average airport passenger; their baggage characteristics, their use of baggage carts, and their mobility issues vary from airport to airport. International passengers have different characteristics than domestic passengers. Business travelers have different characteristics than leisure travelers. Airports serving metropolitan cities have different types of passengers than those serving vacation destinations. All of these characteristics should be considered when developing passenger space allocation parameters.

Passenger space allocation parameters include personal space of the passenger and allotments for carry-on baggage and, if appropriate, checked baggage. Additional allotments for baggage carts (if permitted on the system), strollers, wheelchairs, and walkers may also be considered. Figure 8.4.2-1 illustrates an example of passenger space allocations.

Once passenger space allocations have been defined, they may be used to determine appropriate boarding queue and circulation space requirements. In addition, determination of the percentage of baggage-cart users, families with small children in strollers, and mobility-impaired users is necessary for determining vertical circulation mode choice.

Establishing performance criteria and defining the level of service for passengers is necessary to size stations and to determine the required capacity of vertical circulation and passenger vertical conveyance elements. By defining suitable performance criteria and levels of service, ample space and capacity may be provided so as not to limit potential growth, or to avoid providing expensive, excess capacity.

APM station planners may apply commonly used and readily accessible level-of-service recommendations with regard to personal space allocations, such as those suggested in the IATA *Airport Development Reference Manual* or in John J. Fruin's *Pedestrian Planning and Design.* Both of these sources provide level-of-service recommendations for queuing and circulation environments. Airport operators and aviation departments may have internal levels of service to which APM station planners must adhere.



Source: Lea+Elliott, Inc.

Figure 8.4.2-1. Passenger space allocations.

Personal-space level-of-service recommendations commonly use a scale of six levels of service to denote personal space allocations. The highest level of service, A, denotes a personal-space allocation that allows passengers freedom of movement and choice of walk speed and direction of travel. A level of service "C," which is typically defined as the desired design level 85% of the time, provides less freedom of movement and limits walk speeds without unduly restricting movements. APM station planners should base station sizes on the airport's desired level of service.

Performance criteria, such as maximum wait in queue and time to serve all passengers, are also used for station sizing. Maximum wait time in queue is typically used to determine if adequate vertical circulation has been provided. The maximum time to serve all passengers and the maximum time to remove all passengers from a platform are used to ensure that all passengers have been removed from the platform before the next train arrives. This is done so as to mitigate the possibly of accumulating queues that affect the safe and efficient operation of the APM.

Depending on the system configuration, the passenger flows at individual stations will be different. For station sizing, it is necessary to perform additional analyses to quantify the passenger movements through each APM station. Such information will subsequently allow the proper sizing of the station platforms and ancillary service devices such as elevators and escalators. Depending on the needs of the project, this analysis may be adequately performed using spreadsheet tools; however, with large and complex APM applications, computer simulations of the pedestrian flows through the stations are often required (see Appendix E for more details).

Careful analysis of queues on the platform is necessary to determine the required station width. Adequate space must be available on the station platforms to provide the most efficient and effective interface between the APM and the adjacent facilities. If platforms are not adequately sized, the successful operation of the APM may be compromised. Consideration should be given to the queue areas and circulation zone as well as any queues that develop at vertical circulation elements. These are described in more detail below.

Vehicle boarding queue area—The vehicle boarding queue area is a space in front of the platform edge doors where passengers form a bulk queue during the active boarding process. The space allotted to each passenger in this queue area is based on the personal space allocation appropriate for the specific conditions at the airport. It is important that this queuing space not interfere with the circulation of passengers in the station, and that sufficient queuing space is provided to keep boarding passengers from blocking the movement of deboarding passengers. For platforms that have escalators on the station boarding platform, it is critical that the vehicle boarding queue area not encroach on the space where people alight from the escalators, so as to prevent dangerous conditions.

Vertical circulation queue area—The vertical circulation queue area is a space in front of vertical circulation devices where passengers form a bulk queue to access elevators and escalators to leave the station. The space allotted to each passenger in this queue area is based on the personal space allocation appropriate for the specific conditions at the airport. This queuing space should not interfere with the circulation of passengers in the station or encroach on the vehicle boarding queue area.

Circulation zone—The circulation zone is the general segment along the platform used by passengers to enter and exit the station and to access vehicle boarding queue areas and vertical circulation queue areas. The space allotted to each passenger in this circulation zone is based on the personal space allocation appropriate for the specific conditions at the airport and the type of APM. It is also important that the vehicle boarding queue area and the vertical circulation queue area not encroach on this circulation zone.

Size and Number of Vertical Circulation Systems

Vertical circulation systems typically found at APM stations where vertical level changes are required are escalators, stairs, and elevators. The size and number of these vertical circulation systems should be carefully planned to provide the best interface between the APM station and the adjacent facility. In this section, the general approach to determining the size and number of vertical circulation systems will be discussed. The characteristics of each of these systems are described first to facilitate the discussion.

The calculation of vertical circulation requirements begins with determining the passenger demand for each type of system. The choice of using stairs, elevators, or escalators is influenced by several factors. First, the characteristics of the passengers, their baggage, whether they use a baggage cart, and their mobility issues are considered. Passengers with baggage carts and wheelchairs must use elevators. Some passengers with strollers, mobility concerns, and/or large baggage may choose to use elevators. For all remaining passenger types, their choice may be influenced by other factors.

The ease and convenience of accessing each of the options, and the elevation change for the vertical transition, may impact the mode choice. If stairs are placed directly next to the escalator system and the level change is only 15 to 20 ft, some passengers who are fit and fully capable of physically using the stairs will choose to do so. Descending movements will see a greater percentage choosing stairs than ascending movements. As con-

gestion builds at the load point of the escalators and elevators, the percentage of passengers choosing to use the stairs will increase. Stairs need to be readily accessible along the path of the passengers, or they will typically be bypassed. Some stairs are designed and located to be only, or primarily, used for emergency access/egress.

Once the demands for each type of system have been determined, analytical models are used to determine the number of elements required to satisfy level-of-service requirements and other criteria. Both static (spreadsheet) and dynamic (simulation) models can be used to model the vertical circulation elements. Static modeling can be a valuable tool to assess the proper layout and integration of escalators and elevators into an APM station, while dynamic modeling can provide a more realistic understanding of the complexities of the simultaneous passenger flows and queue buildups occurring in between successive APM vehicle arrivals. The paragraphs below describe the analysis for both escalator and elevator systems.

Escalator systems—In the case of escalator systems, the distinguishing feature affecting capacity is whether the escalator serves as a descending escalator or an ascending escalator. A descending escalator has a lower capacity (generally) than that of an ascending escalator due to a person's natural hesitation to be sure they have their footing before the vertical drop begins. The other factor with an escalator is that passengers with baggage board at a slower rate than passengers without baggage. For these reasons, the capacity of an escalator system with a 40-in. tread has been observed to range from 40 persons-per-minute for landside passengers with carry-on and checked baggage, to 50 persons-per-minute for airside airport passengers with only carry-on baggage. Figure 8.4.2-2 illustrates some examples of 40-in. escalator capacities.

The required number of escalators should be considered when determining the overall platform width. In addition, the queuing requirements at the escalators may influence overall platform length. Consideration should be given to providing redundant devices to provide capacity during peak conditions in the event any escalators are out of service.

One consideration of an escalator design that helps minimize the capacity impacts described above and speeds the boarding process is to provide more flat steps before the ascent or descent begins, such as a design that provides three or four flat steps at the boarding location.

Elevator systems—The capacity of an elevator system that only serves two levels is easily analyzed in terms of door width (affecting boarding rate), the average dwell time, and the service time (the average time between another elevator cab being available to board). The average waiting time for this simple configuration would be determined by the round trip time of one cab divided by the total number of elevator cabs serving the circulation core.

However, for elevator systems that serve more than one level, and especially systems that may serve different levels for different types of passengers (i.e., air passengers versus airport employees), it is more difficult to establish an average waiting time without a detailed elevator system analysis. (Simulations may be required for the most complex of elevator systems.) In the planning phase, a planning factor may establish the elevator average service time goal, and then the planning and design process would define the number of elevator cabs that would be required to provide that service time.

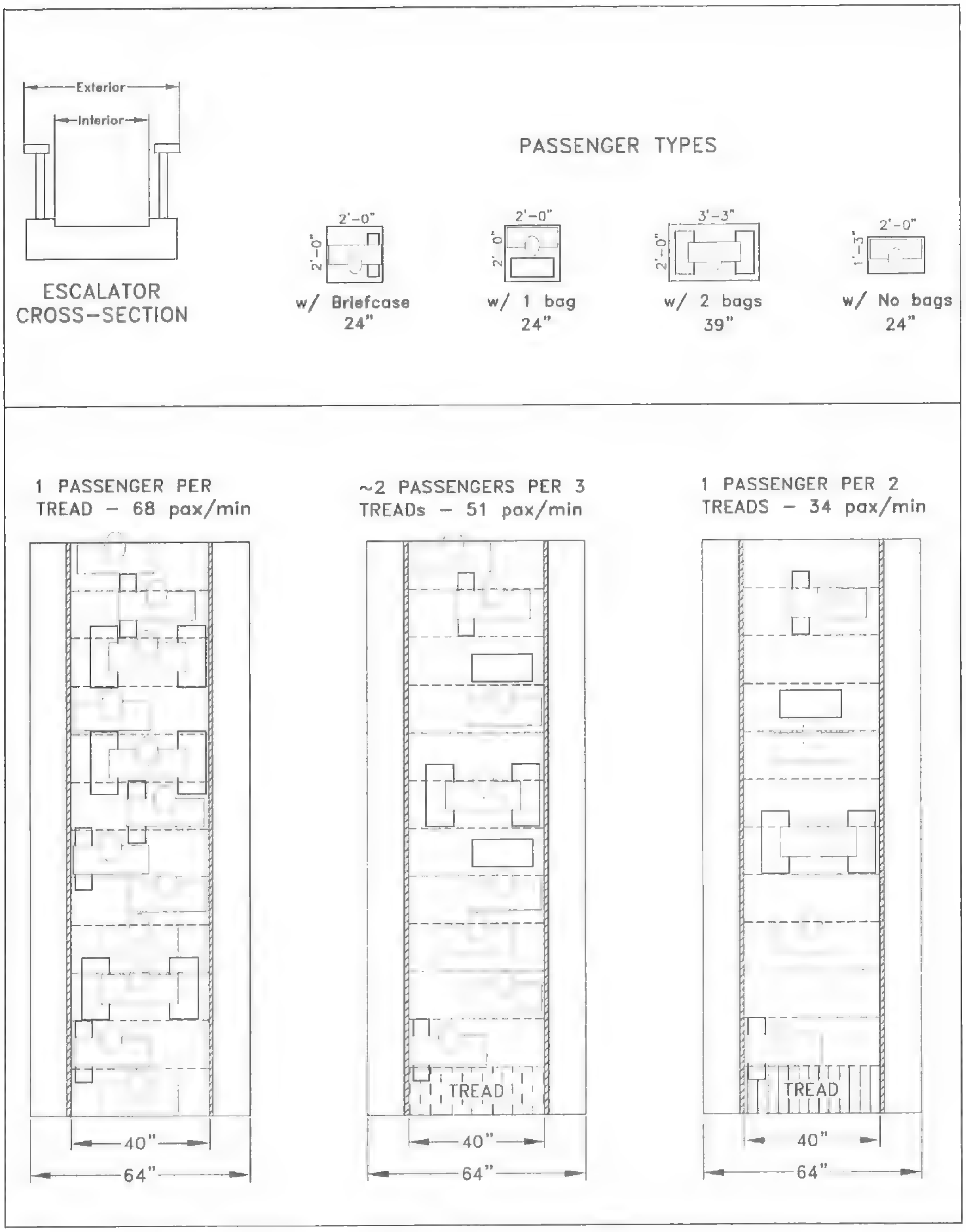
The required number of elevator devices should be considered when determining the overall platform size. In addition, the queuing requirements at the elevators may influence overall platform size. Consideration should be given to providing redundant devices to provide capacity during peak conditions in the event any elevators are out of service.

From a safety point of view, it is very important to provide adequate passenger egress capacity to ensure that the passengers alighting from the APM to the platform can be dissipated through the available vertical circulation prior to the next APM train arrival. Consideration should be given to the fact that escalators and elevators can be unavailable for use due to either unforeseen failures or preventative maintenance.

The dynamic modeling of vertical circulation elements requirements for APM stations is covered in greater detail in Appendix E.

Code Compliance

Transit station design must comply with all applicable codes. In particular, emergency egress codes such as National Fire Protection Association's NFPA 130 should be considered in planning for the potential emergency evacuation of the station and associated APM trains. Appendix D of this guidebook provides an annotated bibliography of agencies whose codes and standards affect APM systems. Building codes/standards and fire codes establish much of the capacity requirements for vertical circulation, and those sources should be consulted to obtain the methodology for calculating the parameters that determine sizing of the vertical circulation elements for emergency conditions. One key aspect of such calculations is that the vertical circulation systems may be required to cease operation under certain emergency scenarios, and the escalators may then be treated as fixed stairs within those circumstances.



Source: Lea+Elliott, Inc.

Figure 8.4.2-2. Escalator capacity examples.

NFPA 130 and local building codes sometimes conflict, and these conflicts must be resolved to arrive at a station design. For example, in the case of designing emergency egress, NFPA 130 often has more stringent requirements than the local building codes in effect for an APM project. In most cases, the more stringent requirement should be followed.

The outcome of emergency egress analysis may indicate that additional vertical circulation elements are required to meet the code(s) as required by the local authority having jurisdiction. In this case, the station design must take these findings into consideration.

Minimum Station Platform Size

Once the number and size of the vertical circulation elements have been determined, along with all appropriate queues, the minimum station platform size can be established. The minimum size of each platform is based on the sum of the queues,

circulation zones, and vertical circulation elements. The combination of elements to define the minimum width and length depends upon the station configuration and location of the vertical circulation elements.

The overall station size will be based on the minimum width and length (although it may be larger) and should take into consideration any internal columns, equipment rooms, and other facilities that will be located at the station. The station size should accommodate all of these elements to provide an efficient and effective interface between the APM and the adjacent facilities.

8.5 Maintenance and Storage Facility

The MSF provides a location for all vehicle maintenance and storage as well as administrative offices. The maintenance functions include vehicle maintenance, cleaning, and washing; shipping, receiving, and storage of parts, tools, and spare equipment; fabrication of parts; and storage of spare vehicles.

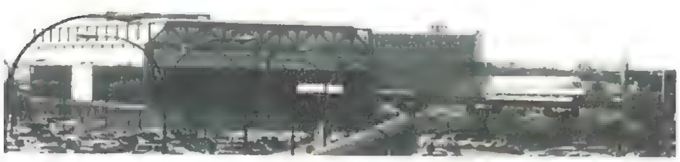


Photo: Lea+Elliott, Inc.

Offline Maintenance Facility at Newark

For the larger APM systems (non-shuttles), the MSF is typically a facility located separate from the operating alignment. Vehicle testing and test track functions are generally performed on the guideway approaching the MSF when the facility is separate from the operating guideway.

Photo: Lea+Elliott, Inc.

Online Maintenance Facility at Las Vegas

Simple shuttle systems often have the MSF located under one of the system stations. An example of maintenance below a shuttle station is provided in the adjacent photo of the Las Vegas McCarran airside APM shuttle system.

8.5.1 Maintenance and Storage Facility Planning Criteria

The MSF is the primary location to perform maintenance on the APM vehicles and system equipment; to house repair shops, keep records, and protect spare parts and consumables; and to store the vehicle fleet, any maintenance vehicles, tools, and equipment. This facility can also store vehicles not operating on the APM system guideway. Planning of the MSF (online or offline) should be also based on the specific APM technology and the O&M tasks associated with this technology.

When considering the location of the MSF, it is important to determine whether the facility should be located online, that is within the passenger carrying guideway, or offline in a location outside of the operational alignment. Dependent both on the space available and the size of the fleet, MSFs may be either. In general, smaller shuttle systems are better suited to online MSFs, while larger systems with bigger space requirements often require that the facility be situated outside of the passenger carrying alignment.

Online MSFs are typically located at or just beyond the normal train berthing position at the station. For systems with online MSFs, the trains enter the maintenance area from the passenger-carrying portion of the guideway. The types of maintenance activities that can be performed during the hours of system operation are therefore limited since the trains are maintained while parked at or adjacent to the normal berthing locations. These facilities are typically associated with smaller APM systems such as shuttle systems. The online MSFs are typically accessed from below or the side. The shops, rooms, and equipment are generally located below the guideway and the station platform. An online facility typically has the same functions as an offline facility, but on a much smaller scale. There is no space to store additional fleet in an online facility, so when fleet size exceeds the number of cars that can be berthed at the station, these types of facilities are no longer practical.

Offline maintenance and storage facilities are separated from the main line of operation. The MSF is accessible from the mainline guideway by the ready and receiving spur tracks. The ready spur track is where trains are staged prior to entering service. The receiving spur track is where trains are removed from service. Offline MSFs are typically associated with larger APM systems and can accommodate a larger fleet of vehicles. The facility is typically composed of a large building where the vehicles are maintained and repaired, train yard, test track, wash facility, and a vehicle storage area. Regardless of where it is situated, the MSF building includes areas such as

maintenance and repair shops, spare parts storage, administration offices, locker rooms, meeting rooms, and all other facilities needed to maintain the system. However, an offline MSF will typically also have a train yard composed of several tracks joined by switches, in order to allow effective routing between the maintenance building, vehicle storage area, vehicle wash facility, and test track.

Maintenance Building

The MSF should be designed to accommodate maintenance activities that will support the desired level of service and system availability. When planning the MSF, specific functional spaces should be considered to accommodate the different types of services and activities. Types of functional spaces that should be considered include administrative areas, personnel wash areas, locker rooms, eating/break areas, vehicle maintenance areas, mechanical equipment shops, electrical equipment shops, electronic equipment shops, tools and equipment storage, vehicle wash areas, vehicle test track, and vehicle storage areas. The following paragraphs discuss the more important considerations associated with these spaces. The detailed considerations are usually investigated during the subsequent design process, but it is important to be sure that adequate space of the correct types is provided during system planning.

Administrative and personnel spaces—Provisions for office and work spaces for personnel should be included in the MSF plan. Male and female toilets, showers and locker rooms, and a common break room should be included. Sufficient office space for the O&M staff is needed and should be separated from the noise, dust, and odors of the maintenance areas to the extent practical. See also Section 8.8.

Vehicle maintenance areas—Simple shuttle APMs usually have maintenance bays under one of the system's end stations. Many of the items that are discussed below, for larger pinched-loop systems with an offline MSF, must also be accommodated in some manner for shuttle systems. When planning the vehicle maintenance areas or bays, several factors should be given consideration. Below-car maintenance pits can make APM vehicle equipment accessible without jacking, and should be considered where appropriate. Jacking areas with clear overhead space should be provided in case undercar equipment must be removed to be repaired. Access to the tops of vehicles should be provided. A separate power source should be provided for the maintenance bays because the cars will be removed from rail power when entering those areas. Overhead cranes will be needed for vehicles with roof-mounted HVAC equipment. The routing of electrical and mechanical equipment should be designed to prevent tripping hazards, injuries, and other safety hazards. Paths for forklifts, pallet movers, and other mechanical equipment must provide access to the vehicle maintenance area.

Mechanical equipment shops—Maintenance of mechanical equipment usually requires the use of compressors, grinders, cutting tools, and other tools. Separate shop areas should limit the transmission of noise, vibration, and odors. Some vehicle components such as HVAC equipment, drive-train equipment, and compressors are bulky and will require clear paths for forklifts, hand trucks, pallet movers, or other wheeled carts. Provisions for this equipment, such as wide door openings and smooth floors, will improve access to the repair space. Solvents and lubricants are often used in these spaces and considerations for material storage, ventilation, and slip-resistant flooring should also be incorporated.

Electrical equipment shops—Electrical shops have similar requirements as mechanical shops. Some of the electrical equipment, both on the vehicles and on the wayside, are bulky and operate at voltages at or above the normal building voltage. Considerations for the movement of bulky items should be given to these shop spaces as well. Power requirements to energize the equipment that is being serviced can be important for testing or troubleshooting.

Electronic equipment shops—These are similar to electrical shops except that electronics and their test equipment are more sensitive to humidity, temperature, and vibration and thus require a separation from other areas (mechanical and electrical shops can be in open areas) to provide a cleaner environment with HVAC and dust filtering. This equipment can be sensitive to static discharge, so additional grounding is usually necessary.

Storage areas—Storage for replacement parts, tools, test equipment, chemicals, and documents should be provided. Supplemental fire protection for storage of rubber tires, solvents, or combustible items should be performed according to local fire codes. Certain types of materials, such as batteries, can necessitate the use of spark-proof fixtures, special ventilation, spill containment, or other special considerations. Storage of electronic equipment can have additional environmental requirements as well.

Adequate space for repair manuals and maintenance records should be provided. These are typically kept in separate maintenance offices. If maintenance records are maintained electronically, which is normal, a provision for access to the database from the shop areas is necessary.

Vehicle Test Track

Vehicles must undergo thorough safety testing following certain maintenance activities before they are returned to passenger service. If the MSF is an online facility, the vehicles

are tested on the mainline guideway. If the MSF is offline, it is useful to have a separate, dedicated test track so that there is no service disruption on the passenger-carrying portion of the system while dynamic tests of the cars are performed. The test track should be at or near the maintenance bay exit track. See also Section 8.8.

Vehicle Wash Areas

Vehicle washing is performed manually for small APM fleets, particularly for a shuttle system. For larger systems, automatic washing of the vehicle exteriors should be performed at the MSF. Adequate space for heated water systems, detergent storage, and wastewater recycling should be included. The washing units are typically included in the APM supplier's contract. The wash facility should be accessible by ground vehicles for equipment servicing and should allow efficient movement of the APM trains through the facility. Interior cleaning of the vehicles can occur in many areas—in a covered area outside the wash facility, at the inspection or maintenance bay locations, or at a covered storage area. Provisions for undercar cleaning should also be considered. This uses high pressure water, steam, or air to remove grime and should follow manufacturer's recommendations. Undercar access and containment of contaminants should be included in the design of this area. See also Section 8.8.

MSF Yard Tracks

Yard tracks are an integral part of the MSF site design for APMs with offline MSFs and are used to transfer the APM trains to the MSF building and bays, storage areas, car wash, and test track. Adequate space for switches and ladder tracks (or in some site-constrained situations, traversers) must be included in MSF planning. The yard tracks should allow efficient train movement to and from these functional areas. Simple shuttle systems with online MSFs do not have yard tracks. The yard can have manual or automated vehicle control. An automated yard can improve the efficiency of moving trains but has potential hazards associated with the driverless movements. These hazards should be considered during the design process. Alternately, all train movements from the MSF ready and receiving tracks into the MSF yard tracks could be conducted under local manual control with hostlers driving vehicles.

Vehicle Storage Area

With online MSFs, trains are stored in the stations, and there are usually no spare vehicles to be stored. An offline MSF vehicle storage area ideally will protect the fleet from environmental conditions. The storage area should be adequate to store the APM fleet, unless some trains can be stored in the MSF bays or in stations. Convenient removal and return to passenger service from these storage areas should be provided, and where possible, there should be multiple routes into and out of any storage area.

Site and Architectural Considerations

In addition to easy train access to the mainline, an offline MSF should have convenient access for deliveries of materials by large trucks. Many facilities have incorporated loading docks to make these deliveries more efficient. The building interior should contain open maintenance areas, including maintenance bays with pits, enclosed workshops, administration areas, and personal areas. In many cases, the APM system, including the MSF, must be designed to be expanded in the future. Consideration should be given to possible expansion of the MSF building and storage areas during the planning process. APM system extensions (new guideway and stations) often require not just an expansion of the MSF but a relocation of the entire facility. While relocating an MSF can be a challenging exercise, the initial cost savings (reduced guideway and associated civil facilities) of a temporary (initial) MSF location is often the deciding factor in the planning process.

Facilities for other functions, such as the central control facility, propulsion power substation, and APM equipment rooms, are often co-located with the MSF. These functions have very specific requirements of their own and should be carefully considered during the MSF design process. These functional spaces are discussed in subsequent sections.

8.6 Central Control Facility

All APM systems include command, control, and communications equipment to operate the driverless vehicles. Each APM system supplier, based on its unique requirements, provides different components to house the automatic train control equipment. ATC functions are accomplished by automatic train protection, automatic train operation, and automatic train supervision equipment.

ATP equipment functions to ensure absolute enforcement of safety criteria and constraints. ATO equipment performs basic operating functions within the safety constraints imposed by the ATP. ATS equipment provides for automatic system supervision by central control computers and permits manual interventions/overrides by central control operators using control interfaces.

The APM system includes a communications network monitored and supervised by the central control facility. This network typically includes a station public address system, O&M radio systems, emergency telephone, and closed-circuit television. The basis for many of these communication requirements are emergency egress codes such as NFPA 130.

The CCF of an APM typically houses:

- The consoles and displays that the system operator(s) use to supervise all aspects of system operations—the central control room (CCR); and
- An adjacent central control equipment room which houses the central control computers; audio, video and data communications equipment; an uninterruptible power supply (UPS) that is capable of supporting all CCF loads; and a training room.

For large, complex systems, the CCF is typically located in dedicated rooms within the MSF. As discussed in the MSF section, the MSF location for larger systems is sometimes relocated as the APM system is extended, so a co-located CCF would have to be moved as well. Some smaller, less complex systems, like many of the airport shuttle systems, may have the APM central control integrated into the airport operations center. Other possibilities include location in separate stand-alone buildings or in a dedicated room within another facility such as an airport terminal. Regardless, the function, equipment, spaces, and features of the CCF are relatively standard.

The typical CCR contains an operator's console with integrated operator workstations for the supervisory control of train operations, the power distribution system (PDS), and all audio and video communications systems. For small systems, there may be a single workstation (although full redundancy is recommended) from which a single central control operator (CCO) can manage the entire system. For larger systems, there may be two, three, or more separate and/or redundant workstations, each with either full function or single function (e.g., train operations, PDS, and/or communications) capabilities.

Redundant CCF equipment can be less complex than the primary CCF equipment. An accepted guideline is to provide redundant and/or fail operational configurations of CCF equipment that ensure that no single failure of that equipment will ever result in the CCO being unable to perform a necessary function. Train operation workstations typically provide a system schematic display with indications and alarms and operator command/control interface capabilities that allow the CCO to supervise the movement of trains throughout the system through interfaces with the ATC system. The PDS workstation provides a single-line electrical power schematic display with indications and alarms and operator command/control interface capabilities that allow the CCO to supervise the supply of power throughout the system.

The communications workstation may be one multifunction workstation or several individual workstations with indications, alarms, and command/control features as required to interface with the public address, operations and maintenance radio, and video surveillance (CCTV) systems. Typically all audio communications are monitored and recorded for future reference in the event of a system incident. Usually there is one master CCTV monitor at the workstation and a second monitor for selectable playback of recorded images. Typically a bank of video monitors displays continuous video images from throughout the system. Finally, there are often large monitors that show the system schematic and the location/status of all trains and status of all stations. Depending on the size and complexity of the system, there is wide variation in the quantity, layout, location, and allocation of features, functions, and equipment within the CCF.

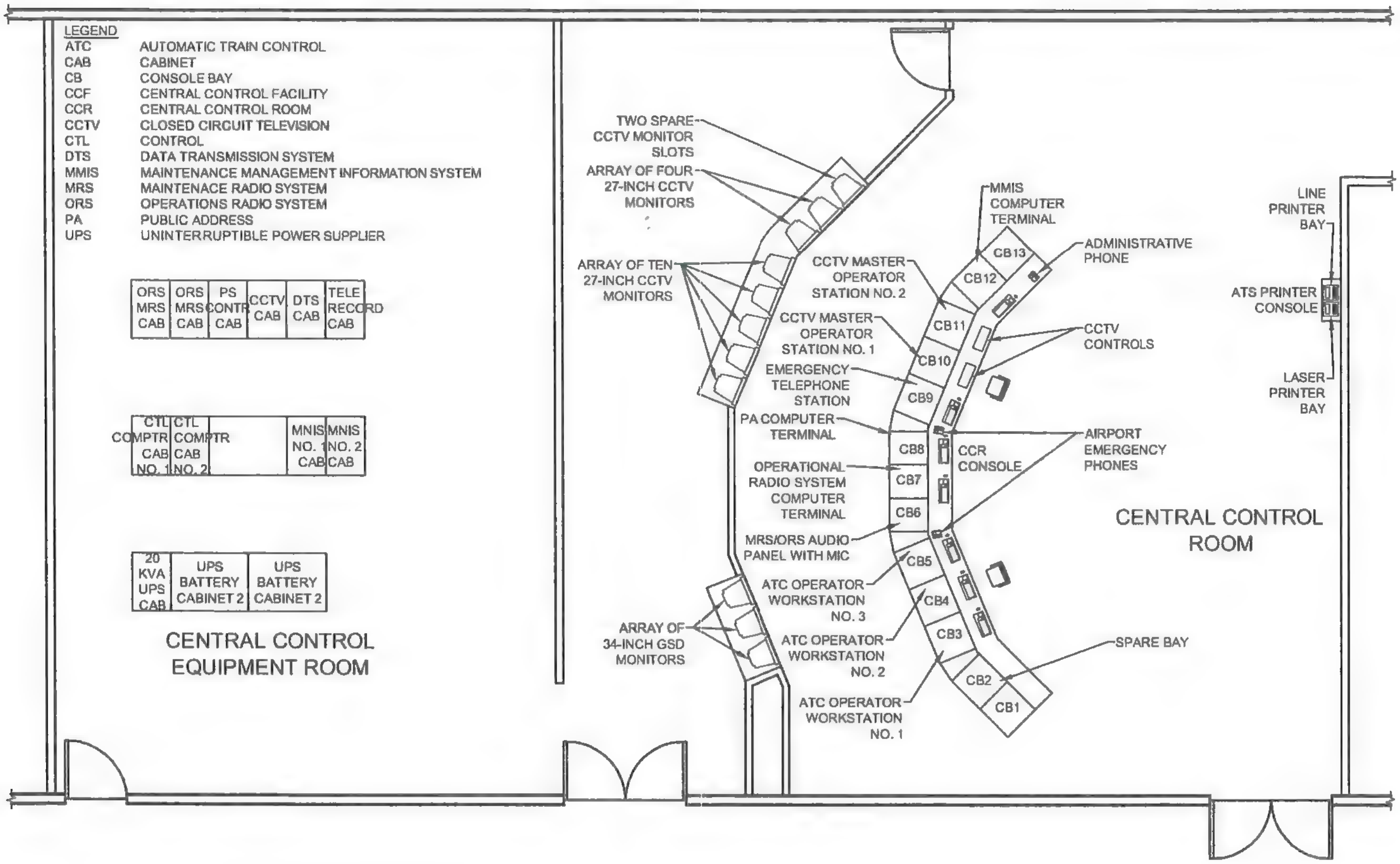
A typical CCF, including a central control equipment room and a separate CCR, is shown in Figure 8.6-1. This sample layout is for a three-station, pinched-loop airport APM that operates four two-vehicle trains during peak operation, has an offline MSF, and a total fleet of 12 vehicles. The central control console is designed for two CCOs: one to manage train operations and PDS, and the other to manage communications, including CCTV and emergency telephones. A common area between the two CCO positions allows both to access the radio (operations and maintenance) and public address audio interfaces.

8.7 Power Distribution and Utilities

APM systems require electric power to operate. Power is required for vehicle propulsion as well as for all controls and monitoring functions. Power is usually obtained from the local utility company, so coordination with the utility company is required from the planning stage of the project to ensure that sufficient power can be supplied at designated APM substation locations. An APM system needs to be designed to continue operating even if one PDS substation goes out of service. The PDS for propulsion and auxiliary loads is typically provided as part of the APM supplier's scope of work.

8.7.1 Propulsion and System Power

Electric power is required to propel vehicles (propulsion/traction power) and energize system equipment. Propulsion and system power are typically configured such that system operation power will be supplied by power substations spaced along the guideway. The substations house transformers, rectifiers (if required), and the primary and secondary switchgear power conditioning equipment. Power distribution can be provided either as three-phase AC or DC. The distance between substations for AC systems is limited to about 2,000 ft, whereas for DC systems the distance is typically limited to one mile. Housekeeping power for lights and convenience outlets is normally distributed from general-purpose circuits located within the facilities housing APM system equipment.



Source: Lea+Elliott, Inc.

Figure 8.6-1. Example of typical CCF.

8.7.2 Local Utility Interface Requirements

In planning an APM system, an important element is the estimate of electrical power demand. Power demand is a function of the length of the system, fleet size (particularly the peak period operating fleet), peak period train headways, type of vehicles and propulsion, and whether the PDS is AC or DC. Once the APM system alignment and the station locations are established, a train simulation must be run to establish the number and length of trains required to provide sufficient system capacity to meet the ridership demand. Data output from the train simulation is then used to perform a power analysis to determine the location, size, and quantity of substations required to power the system. The power analysis typically determines the utility feeder requirements and includes calculation of root-mean square (RMS) and peak loads at each substation and for the entire system. This is the minimum information required by the local utility company to plan and provide the necessary feeders at specified locations.

The local utility company should be involved at the initial planning stage of the project. Coordination includes not only the power demand of the system and each substation, but also the location, redundancy requirements, interfaces, and division of responsibility between the local utility and the future APM supplier. The division of responsibility varies depending on the airport's desires and prior agreements with the local utility. In some cases, the local utility's responsibility ends at the closest utility vault, where the APM supplier will interface their primary power equipment, which is then typically connected by the local utility. In other cases, the local utility will provide the primary switchgear or may even provide the traction power transformers based on the system supplier requirements. In this case the local utility provides and maintains the primary equipment on behalf of the airport.

For an airport that has an electrical operating department, there may be existing arrangements between the airport and the supplying utility that would establish a framework for negotiations. The particular relationship that each airport has with its utility will determine the appropriate interface between the two entities.

APM systems are designed to include sufficient redundancy to maintain specified system availability requirements, typically 99% or greater. Thus the local utility is usually required to provide redundant power feeds: one used as the primary feed and the other as the secondary feed. In the event of a primary feed failure, switching equipment automatically switches to the

secondary feed until the primary feed power is available. This ensures that the primary power feeders do not present a single point of failure that would shut down system operation.

8.7.3 APM Substation Requirements

Many factors must be considered to determine the APM substation quantities, electrical size, locations, and facility/space requirements. A key factor is whether the system will use AC or DC distribution, since their size and the length of guideway served by each differs considerably. The APM industry has moved primarily to DC distribution systems. AC distribution systems are typically now used only on smaller APM systems such as short shuttles.

The advantage of using AC distribution is that the physical size of the substation is smaller than that for a DC substation. DC substations require more facility space because they require rectifiers and can provide power to longer guideway segments since there is less voltage drop per unit length compared with AC power. This equates to larger equipment sizing to accommodate this increased load. AC distribution requires substations at more frequent intervals, 2,000 ft or less, due to voltage drop. This requires more substations along the alignment as well as an increased number of feed points to the guideway. DC distribution can provide power to a much longer guideway: typically 5,000 ft or more between substations. Although a DC substation requires more and larger equipment, the greater distance between substations results in fewer substations and typically equates to significant cost savings.

APM substations typically range in size from 500 KVA to 1500 KVA. The electrical size of the substation depends on several factors, including length of guideway being powered by the substation, minimum headway of the APM system, size of the trains (large or small APM vehicle, number of cars per train, etc.), and the train passenger load.

8.7.4 Station Auxiliary Power Requirements

Each APM station has train control equipment, supervisory control and data acquisition (SCADA), station platform doors, PA, CCTV, local auxiliary power distribution equipment, and other electrical equipment required for system operation and monitoring. As most of this equipment is critical to the operation of the system, much or all of this auxiliary system power is provided through UPS. Electrical power, either from the APM traction power substations or airport-provided facilities, will charge batteries, which in turn power the equipment, so that if there is a power outage, the equipment will function for a given time period. Typically the station auxiliary power loads range from 25 KVA to 100 KVA, depending on the size and complexity of the system. For example, some APMs have track switches that may be powered, controlled, and monitored through the auxiliary power source. UPS systems are typically supplied as part of the APM system supplier's scope of work.

If there is a significant distance between stations, an intermediate remote equipment room may be required for train control equipment (and possibly switches) that serves this segment of guideway. Remote auxiliary power would be needed for these loads.

8.7.5 Maintenance and Storage Facility Power Requirements

The power requirements for both the MSF building and the APM-related equipment located therein must be considered in overall APM planning. Power requirements for the facility itself can range anywhere from 500 KVA to 1,000 KVA, depending on the size of the facility. This power is usually obtained from the local electric power company and is not part of the APM supplier's scope of work. The APM-related equipment, maintenance bay stingers, and propulsion power for guideway leading into and out of the MSF is provided as part of the overall APM system. Depending on the size of the facility, the number of trains it can accommodate, and the quantity of electrical tools and equipment required to maintain the fleet, the power required can range between 250 KVA and 750 KVA on a typical large APM system.

8.8 Appurtenant Facilities—Planning Criteria

In addition to the major fixed facilities documented in this chapter, most APM systems also include the following miscellaneous facilities that can be categorized as appurtenant facilities. These include administrative offices, APM system equipment rooms, train wash facility (different types), and the train test track.

Administrative offices—The APM system's O&M staff requires space to conduct administrative functions. These administrative offices are commonly located within the maintenance facility or adjacent to the central control facility, but may be located at any location convenient to the particular operating requirements of the system. The functional requirements for the system's administrative offices are typical of any professional office environment. While usually separate from maintenance personnel offices, efficiencies may be gained by sharing certain functional spaces such as a conference room. Specifically, the administrative offices should accommodate the following functions/spaces: lobby/reception area, private offices, support (cubicles), conference room, copy/file room, bathrooms, small kitchen, storage, and janitor's closet.

Equipment rooms—Equipment rooms are typically located at each station, central control, the maintenance facility, and along the wayside as needed. These rooms house control and interface equipment for the station doors, dynamic signage, CCTV, automatic train control equipment, UPS equipment, PA system equipment, and other related electronic equipment.

Although the specific layout of the rooms should be coordinated with the APM supplier's specific equipment requirements, some general rules apply. Cable distribution and wiring access either above or below the equipment should be considered during the room's design. If below the equipment, then sufficient clear ceiling height is required. If above the equipment, a greater clear ceiling height is required. Specific heights should be determined on a case-by-case basis. A minimal clearance of approximately 3 ft around the perimeter of all major equipment cabinets is required for access.

Train wash facility—There are generally three types of train wash facilities that correlate with the size of the system and the overall vehicle fleet size. These facilities, in ascending order of sophistication, are as follows.

- Hand wash facility—For small APM systems (particularly shuttles), a hand wash facility is adequate. The facility typically consists simply of an online designated area to wash the trains that is capable of containing, and properly draining, the wash water without overspray impacting the public or public areas. Washing may be accomplished totally by hand or with the aid of a pressure washer. It should be noted that even systems operating in a tunnel environment require occasional washing.
- Gantry wash facility—A gantry wash is typically an offline, fully automatic wash facility where the vehicle remains stationary within a wash bay. The bay may be a partial enclosure or a small fully enclosed building. The wash can consist of high pressure wash and rinse or can incorporate spinning brushes that automatically move around the vehicle. Gantry washes are space efficient because they can offer fully automated washing. However, they typically accommodate only one vehicle at a time. Thus, systems with multi-car trains typically require uncoupling and coupling of vehicles in order to wash them.
- Drive-through wash facility—A drive-through wash is typically an offline, fully automatic wash facility where the train drives by fixed washing devices. As with gantry washes, a drive-through wash facility may incorporate high pressure wash and rinse with water only, or for highest effectiveness, may incorporate spinning brushes. In this case, the brushes typically spin in a fixed position as the train moves past them. The ideal location for a drive-through wash is on the same section of guideway that serves as either the receiving or departure tracks within a maintenance yard. This location will allow all incoming or outgoing trains to pass through the wash facility without the need of a separate, or additional, section of guideway.

Test track—A test track is a dedicated offline guideway used for the testing of trains to ensure that they are ready for passenger service. A test track is not applicable to smaller shuttle systems since all maintenance and testing occurs online. For larger systems with an offline maintenance facility, a test track provides a desirable maintenance tool. These test tracks are typically located directly adjacent to or as part of the maintenance facility yard. Ideally, the test track should be straight and level and allow maximum length trains to accelerate and decelerate to and from maximum cruise speed, thus allowing for brake testing. The downside of such test tracks is their space requirement and associated capital (system and facility) costs. Some airport environments may not have the physical space available to accommodate such a test track. In such cases, some aspects of the trains' electronic, electro-mechanical, and physical functions must be tested online without passengers.

8.9 Safety and Security Planning Criteria

Airport APMs are transport elements that are critical to airport operations. Thus the safety and security of the APM system and infrastructure, and its passengers, maintenance personnel, and all other persons that enter the APM environment, are of paramount importance.

8.9.1 Comprehensive Approach to APM System Safety and Security

Airports usually have a comprehensive approach to safety and security; the APM should be included as an integral part of this program. Any APM safety and security program should be continuous, from the start of planning, through procurement, detailed design, installation, testing and certification, and passenger service. The safety and security philosophies of current APM system suppliers and contractors have evolved from the rail transit, aerospace, and defense industries, as well as occupational safety. Working in an airport also requires a clear understanding of the safety and security principles of the aviation industry, particularly with respect to construction safety within the airport environment and FAA/TSA security at the airport.

Comprehensive APM system safety and security programs typically include the following components:

- System safety program plan (SSPP),
- System security plan (SSP),
- Design safety principles,
- Hazard resolution process,
- System verification and demonstration,
- System safety certification,
- Construction safety program,
- Employee safety program,
- Emergency preparedness program,
- System operation plans and procedures,
- System maintenance plans and procedures,
- System training program,
- System operational monitoring plan, and
- Accident reporting.

In the United States, the American Society of Civil Engineers (ASCE) has created and published ASCE Standard 21 (Automated People Mover Standards). Part 1, Section 3 (ASCE 21-05) addresses safety and performance requirements that apply to APM systems. ASCE published a safety and security standard that included requirements that address federal and state regulations for independent safety oversight agencies. Safety and security programs should also adhere to ASCE 21, Part 4 (ASCE 21.4-08).

If required by legislation or regulation, the APM safety and security programs could be subject to the requirements of 49 CFR Part 659 (State Safety Oversight of Fixed Guideway Transit Systems), including the specific requirements for System Safety Program of Subpart 659.15. Although most airport APM systems do not fall under the definition of a fixed guideway transit system, some states have applied these federal regulations to APM systems that are within the jurisdiction of their safety oversight agency (SOA), and this can include airport APMs.

8.9.2 System Safety

System safety is the process, design, and procedures to verify, validate, and certify the safety of the APM system. Construction safety and occupational safety are generally not included under system safety, but are of equal importance and are typically considered in the design and phasing of an APM system.

Fully automated, driverless APM systems have significant safety considerations beyond the typical requirements for manually driven systems and/or automated transit systems with onboard personnel. In addition to safety features typically employed in other forms of passenger transport, driverless APM systems require the following safety considerations:

- Improved vehicle guidance equipment,
- Tipping stability and/or derailment prevention,
- Automatic train control,
- Restricted speed controls for manual operations,
- Automatic doors with closed-and-locked detection,
- Detection of propulsion and braking failures,
- Detection of suspension failures, including wheel diameters and flat tires,
- Provisions against intrusions into the guideway,
- Provisions against obstacles and debris on the guideway,
- Onboard emergency telephones and onboard public address systems,
- Provisions and procedures for evacuations by passengers,
- Regular testing and maintenance, and
- Readiness drills related to safety and emergencies.

All possible hazards related to the particular design of the APM system must be considered in the system safety process. The application of ATC and restricted manual speed controls is often considered to allow a reduction in provisions against collisions with trains, end-of-line buffers, and other equipment. Proper design analysis and hazard assessment are critical in the design and review of vehicle crashworthiness.

APM system safety should not depend on the ability or actions of operating personnel. Special procedures may be necessary to provide passenger safety under certain conditions. For any hazardous condition or emergency, all design conflicts should be resolved in favor of human safety. A hazard management process should be implemented to identify and resolve hazards and safety issues throughout the life of the system.

System safety must be the primary design requirement for an APM system. The entire system must operate safely under all conditions. This includes special designs for safety-critical components; fail-safe or redundant equipment and controls; highly reliable parts; warning devices; failure sensors, instrumentation, and alarms; and fire and smoke detection. Such equipment must be tested frequently, be properly maintained, and also be recalibrated and/or replaced on a periodic basis.

8.9.3 System Safety Program Plan

Typically, the airport is required to develop an SSPP to identify the processes used to address safety during the construction, implementation, and operation of the APM. The SSPP addresses Occupational Health and Safety Administration (OSHA) standards and other regulatory requirements, including airport safety management and reporting procedures. The SSPP should also state the legislative or regulatory authority by which the airport is mandated to develop and enforce safety and security requirements. Enforcement by any SOAs should also be indicated.

The airport should require the APM supplier to develop a technology-specific SSPP. This would expand the airport's SSPP to include: (1) designation of the contractor's safety manager, (2) safety roles and responsibilities for all parties, (3) the hazard identification and resolution process, and (4) an internal safety policy for the commitment of resources.

8.9.4 System Security Plan

The APM is often a primary transportation mode for airport passengers and employees. The airport should update its security plans and security incident response procedures to include the APM, particularly with respect to airport security, passenger segregation issues, and security of the APM equipment and infrastructure.

In the United States, these security plans and procedures are subject to the jurisdiction of the FAA, Department of Homeland Security (DHS), the TSA, and in some cases, U.S. Customs and Border Protection (CBP). Sensitive information in these security plans may need to be released to the airport project personnel and the APM supplier to be incorporated into the APM system and its technology-specific SSP.

8.9.5 Emergency Preparedness Program

The airport should update its emergency response procedures to include the APM with respect to emergency response coordination, airport security, and passenger segregation issues, as well as the security of the APM equipment and infrastructure. The airport should also develop an emergency preparedness program for the APM itself. This should address the duties of the APM operator and all emergency responders for each type of emergency, and safety and security alarms. This program should define the requirements for notification of emergency responders such as fire, rescue, police, and other airport personnel. This emergency preparedness program should also address personnel training and the conduct of emergency readiness drills, and should be closely coordinated with airport emergency procedures and airport security procedures.

8.9.6 Safety Oversight Requirements

Depending upon the jurisdiction, APM safety and security practices may be subject to regulatory oversight by a transportation safety board (TSB), SOA, public utilities commission (PUC), and/or other regulatory authority. Many APMs are operated by self-regulated airport authorities that are not subject to regional or local oversight. In some of these cases, the APM supplier could be subject to safety oversight even when the airport authority is not regulated by such an agency.

Safety Oversight in the United States

Safety oversight of fixed guideway transit systems is required at the state government level under 49 CFR Part 659 when there is a similar transit system operating within that state. States are exempted from these requirements if the transit system is subject to a multi-state safety oversight agency.

APM systems are not included under the federal definition of "fixed guideway transit systems" unless the airport has received funding from the Federal Transit Administration (FTA). APM systems can be considered to be a fixed guideway transit system if the FTA includes the APM system mileage as a part of the FTA's mileage formula for that state. Some other APM systems are still regulated by an SOA or another regulatory authority because of state legislative mandates or precedents prior to the enactment of 49 CFR Part 659.

APM systems in the United States are subject to some level of safety oversight in a number of states, including California, Colorado, Florida, New Jersey, New York, and Pennsylvania. Some states actively monitor APM safety certification and provide regulatory safety oversight, while others are active during APM certification but do not conduct annual or triennial safety audits for APM systems.

Independent Oversight of APM Systems

The requirements of 49 CFR Part 659 set a strong precedent for independent oversight of transit system safety and security processes and performance. Airports should consider developing a system operational monitoring plan that addresses all of the requirements for transit agencies as contained within 49 CFR Part 659. If the airport is not subject to state safety oversight, many of the requirements for the SOA within 49 CFR Part 659 should be considered for application in the APM project.

8.10 System Level of Service

Ridership, system capacity, and system technology will yield, through computation, the level of service experienced by passengers. This can be expressed quantitatively in several ways, including:

- Walk distances;
- Wait times;
- Travel times;
- Trip times (wait time plus travel time); and
- Other experience factors, such as ease of boarding/alighting, noise environment, visual environment, climate control, and safety/security.

Optimizing the passenger experience is the focus of many APM planning methodologies. For an airside APM at a hubbing airport requiring quick and convenient gate-to-gate connections, the passenger experience on the APM can be critical to the airport's success. To the extent possible, methodologies that measure passenger level of service should be quantitatively based. Passenger LOS can be categorized as levels A through F, or varying degrees thereof. This methodology has evolved from pedestrian LOS work in mass transit pioneered by John J. Fruin and more recent airport-specific work by IATA.

When quantitative means of measurement are not possible, planning methodologies may use qualitative criteria. Quantitative LOS analysis using levels A–F typically focus on passenger densities—either static density in queues or dynamic density of passenger circulation.

Examples of APM planning methodologies that focus on passenger LOS are provided in other subsections for alignments, ridership, technology assessments, stations, and train operations. For each of these areas, passenger LOS is a measurement of the passenger experience on the APM transport system. LOS measures include:

- Passenger crowding: density—space for each passenger;
- Trip time: minimizing total trip time, especially the wait-time component of trip time;
- Work effort: minimizing walk distances, steps, level changes, baggage lifting, and so on;
- Ride comfort: minimizing lateral forces on a passenger due to horizontal and vertical curves, as well as acceleration and deceleration; and
- Simplicity: maximizing the ease of use.

8.11 Capital Cost Estimation

Once the physical characteristics of the APM system are defined, estimates can be developed for the cost to build, install, and test the system. These estimates are typically developed on a subsystem-by-subsystem basis, with appropriate contingencies to reflect uncertainties. The use of cost data from prior competitive procurements is of great relevance during this task. When buses or other roadway solutions are considered, estimates must include any special roadways that may be required.

The complexities of APM systems make their cost estimation complex. For planning purposes, a cost estimate does not need to be as detailed as a budgetary estimate. APM planners should, however, recognize that the first number decision makers see will be the ones they expect later when a budgetary estimate is made. The cost estimates used in the initial planning of an airport APM should be representative of the relative differences between each alternative. The emphasis in this section is on estimating costs of the APM system (equipment) as opposed to the civil structures, which follow more typical facility cost estimation methodologies (quantity takeoffs).

8.11.1 Historical Perspective

Cost estimating for the procurement of APM systems is a complex process. Each APM technology is proprietary and functionally unique; therefore, it can be impractical to use traditional cost-estimating methods to develop a budget for a particular application. Usually, it has been more efficient to develop price models based on the unit prices derived from line items and lump sums from similar past projects.

In the past, the majority of airport APMs have been procured with DB contracts, which place nearly all of the risk associated with APM system equipment on the APM supplier. This risk value can be quantified and should be included in the price estimate for the APM supplier. Soft costs for airport administration and project management, as well as design and construction contingencies, should be estimated separately.

The most accurate cost projections are based on historical data that cover unit prices for major subsystems and components, thereby reducing the contingency value needed for unknown elements. It is possible to develop valid budgetary cost estimates using lump sum costs or contingency factors for minor cost elements. It is also possible to use real unit prices for the major cost elements.

8.11.2 Capital Cost Elements

There are a number of capital cost elements of an APM system used for detailed cost estimates. These elements relate to the APM subsystems and include:

- Guideway equipment;
- Station equipment;
- Maintenance and storage equipment;
- Power distribution system;
- Command, control, and communication systems;
- Vehicles;
- Other APM equipment;
- APM system verification and acceptance; and
- Project management and administration.

Many cost aspects of the first four elements involve structures and facilities that are not specific to proprietary APM systems. Contract packaging issues should be considered in the development of budgetary cost estimates for the APM system.

8.11.3 Capital Cost Estimate Methodology

Capital cost estimating for an APM system is typically based on historical data from similar APM system installations. As

no two APM systems are exactly alike, historical data must be processed carefully with respect to several factors that affect the bid prices; including:

Landside/airside—The costs of construction activities at airports vary based on whether the project is located within any of the airport operations area (AOA), secure passenger areas, sterile international passenger areas, main terminal areas, or landside areas. Project costs are also affected by the complexity of construction access between these areas. The historical costs of APM systems generally reflect these complexities. Local airport planners and engineers are generally the best source for facility costs, structure costs, and other civil costs within the airport environment.

Competition—Worldwide, there are a finite number of APM suppliers, and not all can bid on any particular project. The projected level of competition has been found to have a significant effect on the cost proposals from APM suppliers. Therefore, the impact of competition must be considered in normalizing of historical costs of APM systems to the level of supplier competition expected for the APM system under consideration. For APM shuttle systems, the additional competition from cable-propelled technologies may significantly affect the prices of self-propelled APM vehicle technologies. The competitive factor decreases as the length of the shuttle system increases since the cost of cables and cable drives becomes more expensive.

Business strategy—Bidding strategies among APM suppliers vary widely on an individual bid and have varied over time with individual suppliers. An APM supplier's bid price on a project takes into account its costs (material and labor) and profit as well as other overhead factors such as marketing and retaining staff between projects. Other factors influencing a specific bid include overall corporate profitability, expectations of competing suppliers' bid prices, available manufacturing capacity, and long-term dedication to the APM marketplace. An established supplier may underbid a project to maintain their market position. A supplier new to the APM field with a strong corporate backing may underbid a project to get a foothold in the marketplace so they can later show relevant APM experience, which is an important criterion in many APM supplier selections. Finally, as many procurements tie together the capital cost bid with the initial (i.e., years 1–5) O&M cost bid, some suppliers may underbid the capital cost but expect to make it up on the O&M bid or even plan to make it up on the subsequent O&M work when there is limited or no competition.

System headways and train length—The costs of wayside ATC, power distribution segmentation, traction power substation capacity, and related automated functions at central control become more complex with larger operating fleets, longer train consists (vehicles/train), and shorter system headways. Train length and passenger capacity is also a factor in the cost of station platform size, automatic platform door systems, and vertical circulation at stations. Historical cost data should be normalized with respect to such system complexity.

Transportation costs—Historically, transportation costs have been relatively low compared to other APM cost elements, and are generally embedded in unit prices. Almost all of the equipment from the APM system supplier will need to be transported long distances, including some from other countries. Transportation costs associated with APM vehicles and other APM equipment should be calculated and added to unit costs, or as an additive to the subtotals.

Warranty life—For most APM systems, the warranty period begins upon the commencement of revenue service. For many subsystems, standard warranties generally begin when the APM supplier purchases the equipment from the manufacturer. Commencement of revenue service may be 12 to 24 months beyond the standard warranty, and in many cases, extended warranties are not available from manufacturers. Longer construction cycles may result in significantly higher warranty pricing from the APM supplier.

Contract packaging—APM systems are generally developed as a critical part of a major airport redevelopment program or a new terminal project. The work breakdown between the APM contractor, civil contractors working on APM structures and facilities, and other related facility contractors can affect the accuracy of the cost estimate. Program costs are affected due to duplications or omissions in different cost estimates.

Assignment of risk—The typical procurement of an APM system usually results in most of the risks—tangible and intangible—being assigned to the APM supplier. It is possible to reduce the risks to the supplier, particularly in areas related to construction of facilities and structures (e.g., utility relocation). This risk factor is closely tied to the procurement packaging approaches discussed in Section 10.3. Risk-related contract terms and conditions such as liquidated damages, consequential damages, and insurance also can have a significant cost impact.

Taxes—Some airports are exempt from state and local taxes. Those that are not exempt can expect a cost increase of 5 to 10 percent to account for such taxes.

Escalation—Historical APM price data can be outdated, given the limited number of projects in any year. Escalation factors such as the consumer price index (CPI) can be used to convert unit prices from earlier projects to the

present. This should include the effect of the project duration (midpoint estimate basis, for example). Recent (2007–2008) significant cost increases in materials (steel, copper, concrete, etc.) and labor should be considered in any escalation factors.

Currencies—As a worldwide marketplace, the APM industry is impacted by exchange rates of different currencies. Even the North American suppliers procure some of their equipment from abroad. Recent experiences (2005–2008) with the relative strength of the dollar versus the Euro and Yen have resulted in much higher prices than previously experienced. The impact of fluctuating currencies should be considered for certain cost categories.

All these factors combine to make an accurate cost estimate a challenging exercise for any airport. While historical cost normalization is a preferred methodology compared to standard cost estimates, a major challenge is the collection of such historical data and the project-specific details associated with that data.

There are a number of general steps involved in developing a capital cost for an APM system:

Cost element quantification—Each of the major cost elements should be evaluated and selected with respect to units of measurement, quantities, lump sums, or percentages. Some cost elements can be consolidated into larger groups. Quantities for each of the major cost elements should be calculated or computed using preliminary designs and analytical models. Optional features should be evaluated and included, as appropriate. When designs are not available for some subsystems, analytical models should be used to determine the quantities or complexity—for example, for the ATC system. Traction power simulations or power-flow models should be used to determine typical spacing requirements for traction power substations. Platform coverage analyses should be used to estimate requirements for public address speakers and CCTV cameras.

Cost element categorization (standard/historical)—Each of the selected cost elements should be analyzed with respect to whether standard cost estimating or historical data will produce a more accurate result. In general, historical costs are more accurate for APM system elements, whereas standard cost estimating is more accurate for civil and structural elements.

Normalization of historical data—Historical data should be normalized with respect to economies of scale, additives, competition, and currency. Data for major cost elements from different projects often include additives such as design, installation, system testing, training, standard warranties, and subcontractor markups (such as insurance, profit, and contingency). If the cost estimate is based on a price model, it is not necessary to normalize all of these factors, but rather to account for any major price impacts, which could be done simply in varying the contingency factor.

Inflation and escalation—Inflation and escalation should be computed for standard costs and historical costs. Inflation factors should be based on the R. S. Means Building Cost Index (BCI), R. S. Means Construction Cost Index (CCI), or the producer price index (PPI) for the relevant production category. For structures and facilities that can be procured locally, unit costs should also be normalized for the local conditions based on the appropriate BCI or CCI ratios. Standard unit costs should also be escalated to the midpoint of construction using an appropriate rate. Historical unit data are generally inflated from the project bid dates, but also need to be normalized for the midpoint of construction if the duration of the project is anticipated to be much shorter or longer than a typical APM installation.

Additives—Standard cost estimate additives should be determined. Design, installation, testing, project management, profit, insurance, bonds, permits and licenses, taxes, and warranties should be calculated and added to unit costs, or as an additive to the subtotals. Many of these items are generally included in the historical cost data for APM system verification and acceptance and project management and administration.

Line item cost estimation—For historical cost elements, values for the selected cost items can be estimated using quantities and normalized, escalated unit costs. When mixed with historical cost elements, standard cost elements should include additives already included in the normalized data.

Contingency—Standard risk methodology should be used to assign contingency factors to APM system categories. Separate contingency factors should be considered for any civil work performed under the APM contract. Risk assigned to the APM supplier should be considered part of the APM contract. An additional factor for program contingency may also be needed for airport contract management, as well as for any project risk taken by the airport.

Formatting—Completed cost estimates may need to be revised to reflect the airport's preferred format or a format required by another funding agency. Typical cost formats that may be required at certain airports are the Construction Specification Institute (CSI) MasterFormat, the FAA Cost Basis of Estimate (BOE), and the FTA Standard Cost Categories (SCC) formats. APM system data is usually in a different format and might not easily be converted into

these formats; it is therefore included as a single, separate contract price.

The capital cost estimate is often the most important APM analysis performed during the planning process. An overly conservative (too high) estimate can unnecessarily terminate an otherwise viable project, while a low estimate will have negative repercussions once capital prices are received from suppliers. It is recommended that the estimate be compared with cost of the most similar recent APM implementations.

8.12 Operations and Maintenance Cost Estimation

Estimates should be developed for the operating and maintenance costs associated with the planned APM system.

In developing the estimated O&M costs, it is important that timing issues are properly considered. System operation and maintenance activities will continue for many years. Most often, future costs for all alternatives are discounted to arrive at a present value, which can be combined with the estimated system capital costs to establish a theoretical total cost for the alternative. When buses or other roadway solutions are considered, estimates must include the costs associated with their use of airport roadways, such as increased roadway maintenance.

Estimating O&M costs for an airport APM has many of the same complexities as estimating capital costs. The proprietary nature of APM technologies, the competitive climate, contract requirements, and the differences between different supplier technologies will often lead to estimating costs for a generic APM technology, while the historical data is technology specific. Access to historical O&M cost data and an understanding of the specific APM suppliers, their operations, and the previous project's contract/competitive situation is necessary for accurate estimation of O&M costs.

8.12.1 Operations and Maintenance Cost Elements

There are a number of primary cost categories or elements commonly used in the buildup of an O&M cost estimate for an APM system, including:

- Parts and consumables;
- Traction power consumption;
- Guideway heating and rail heating power consumption;
- Operations staffing, including dispatching and operations supervisors;
- Electrical, mechanical, and electronics technicians;
- Maintenance support staff;
- Inventory control and purchasing staff;
- Management and administration;
- Technical support; and
- Utilities.

The methodology for O&M budgetary cost estimating is closely related to operations planning. The following steps are recommended for preparing an O&M budget:

Fleet mileage computation—Daily and weekly peak, off-peak, and night period demand is the basis of determining operating fleet size during these periods. Annual fleet mileage should be computed using the hourly fleet size projections, including any effect for ramp-up and ramp-down between service modes. Energy consumption, consumables, and part consumption can be calculated from the annual fleet mileage.

Total fleet is a combination of the required operating fleet, stand-by train(s), and a number of spare vehicles undergoing scheduled maintenance procedures.

Maintenance staffing requirements—The annual fleet mileage should be distributed among the vehicles in the fleet, including any special vehicle utilization requirements. Annual maintenance requirements and maintenance cycles should be calculated from the annual vehicle mileage. The number of spare vehicles should be used in determining maintenance staffing requirements. Support staffing for vehicle hostling and cleaning services is also required. Small spare fleet sizes and shuttle systems typically require off-peak maintenance activities, which increase maintenance staffing and related management staffing.

Fleet impact on O&M costs—The fleet size of an APM system directly impacts O&M costs. Fewer spare vehicles may require much of the vehicle maintenance activities to be performed in the off-peak hours, often in turn requiring a third maintenance shift with significant additional personnel and higher average wages. Historical data related to staffing requirements and wages should be normalized with respect to fleet size.

Operational staffing requirements—Daily and weekly peak and off-peak operational schedules can be used to determine the basic operation staff requirements. Additional technicians are typically required for recovery and emergency response. Operations of more than 18 hours per day and small spare fleet sizes often require complex staffing schedules, with three shifts or significant amounts of overtime.

Weather-related activities—For at-grade and elevated APMs, historical weather tables from NOAA (National Oceanic and Atmospheric Administration) and/or ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) should be used to estimate the effect of weather-related events, such as snow,

ice, and high winds. These events determine the cost impact for guideway heating, emergency shutdown, and backup operations.

Technical assistance—Due to system complexity, specialty engineering support from the APM system supplier and its major subcontractors often is required on an as-needed basis. These costs are generally included as a lump sum.

Mobilization, training, and demobilization—In many cases, the airport contracts work by the APM system supplier or a third party for operation, maintenance, and/or technical support. The price of such contracting will include the cost of mobilization, training, and demobilization. Mobilization, staffing increases, and training may be amortized over the entire contract, whereas demobilization is usually accounted only during the final year of a contract. These costs should be included in the O&M budgetary cost estimates.

Normalization of historical data—Historical data should be normalized with respect to fleet and staffing size, additives, competition, and currency. It is not necessary to normalize all of these factors since some can be accounted for in the contingency factor.

Inflation and escalation—Inflation and escalation should be computed for standard cost and historical costs. Inflation factors can be based on the CPI or the locally prescribed standard inflation factor. Inflation for parts and consumables can be based on the PPI for the relevant production category.

Additives—Standard cost estimate additives should be determined. Project management, profit, insurance, bonds, permits and licenses, taxes, and warranties should be calculated and added to unit costs, or as an additive to the subtotals.

Contingency—Standard risk methodology should be used to assign contingency factors for operations and maintenance. Risk assigned to the APM contractor or a third party should be considered part of the O&M contract.

System overhead—There should be a separate estimate of airport management and overhead costs. These can be labor, utilities, and general overhead (often a set percentage).

8.13 Resulting APM System Definition

The APM system that results from the above level of design is now ready to be procured. The system has now been defined to the level necessary to develop performance-based technical specifications as part of an overall procurement package that the airport will then put out to the APM supply industry for tender.

The purpose of the planning process for an APM is to confirm the viability of the APM system and, if viable, identify characteristics and costs of the APM system to a degree that will allow the airport to:

- Confirm and provide proper and adequate funding for the APM, and
- Develop the APM procurement documents.

The planning process and its resulting APM system definition provide parameters accurate enough for developing the planning-level estimates of the APM system's initial capital costs and ongoing O&M costs. Cost estimates to this level of detail then allow the airport to place the APM project in its capital budgeting process. For more information on funding and finance, see Section 9.3.

The planning process also results in parameters for APM procurement documents, including system performance specifications. Performance specifications are commonly used in APM procurements, as opposed to a standard CSI specification. The CSI specification is typically used for conventional construction projects. An APM performance specification tells the APM supplier what to design but not exactly how to design it. See Chapter 10 on APM system procurement for more information.

CHAPTER 9

Project Coordination, Justification, and Feasibility

This chapter relates to steps 5 and 6 of the APM planning process described in Chapter 5 and depicted in Figure 9-1. Defining the optimum APM system for a given airport application is an iterative process, as described in the previous chapter. Throughout that process there are overall project justification and feasibility issues that must be considered. Some can be considered early in the APM definition process, while others are better considered when the APM system is well defined. This chapter describes these justifications and feasibility issues that should be considered (assessed) during the project definition so as to ensure that the project is justified and any project aspects that are not feasible are identified as soon as possible.

9.1 Ongoing Project Requirements and Approvals

As the APM planning process proceeds through steps 1 to 4 and the preferred APM alternative is defined, other final issues must be addressed in order to establish the overall feasibility of the project. These final issues are addressed below.

Comparison with other modes—It is recommended that an APM solution be compared with other possible mode choices in order to assure the airport that the APM is truly the best choice for the application. If this was not done by including multiple modes in step 2 of the APM planning process, it may be done at this stage.

Construction feasibility—This focuses on the constructability of a proposed alignment. Although hypothetically desirable, an alignment may be determined to be physically infeasible because of tunneling issues, foundation issues, and/or elevated structural issues. Interfaces of the proposed APM alignment and stations with other facilities are other areas with potential constructability issues.

Securing of permits and licenses—Where appropriate, construction permits and licenses must be arranged.

Coordination with affected agencies—Construction of an APM requires a great deal of multi-disciplinary and inter-agency coordination. All of the affected agencies must be identified and processes established to engage those entities, keep them informed, and obtain their cooperation.

Jurisdictional approval—The preferred system must be approved by the sponsoring organization. This may be a city council, airport board of directors, authority board of directors, or other organizational entity.

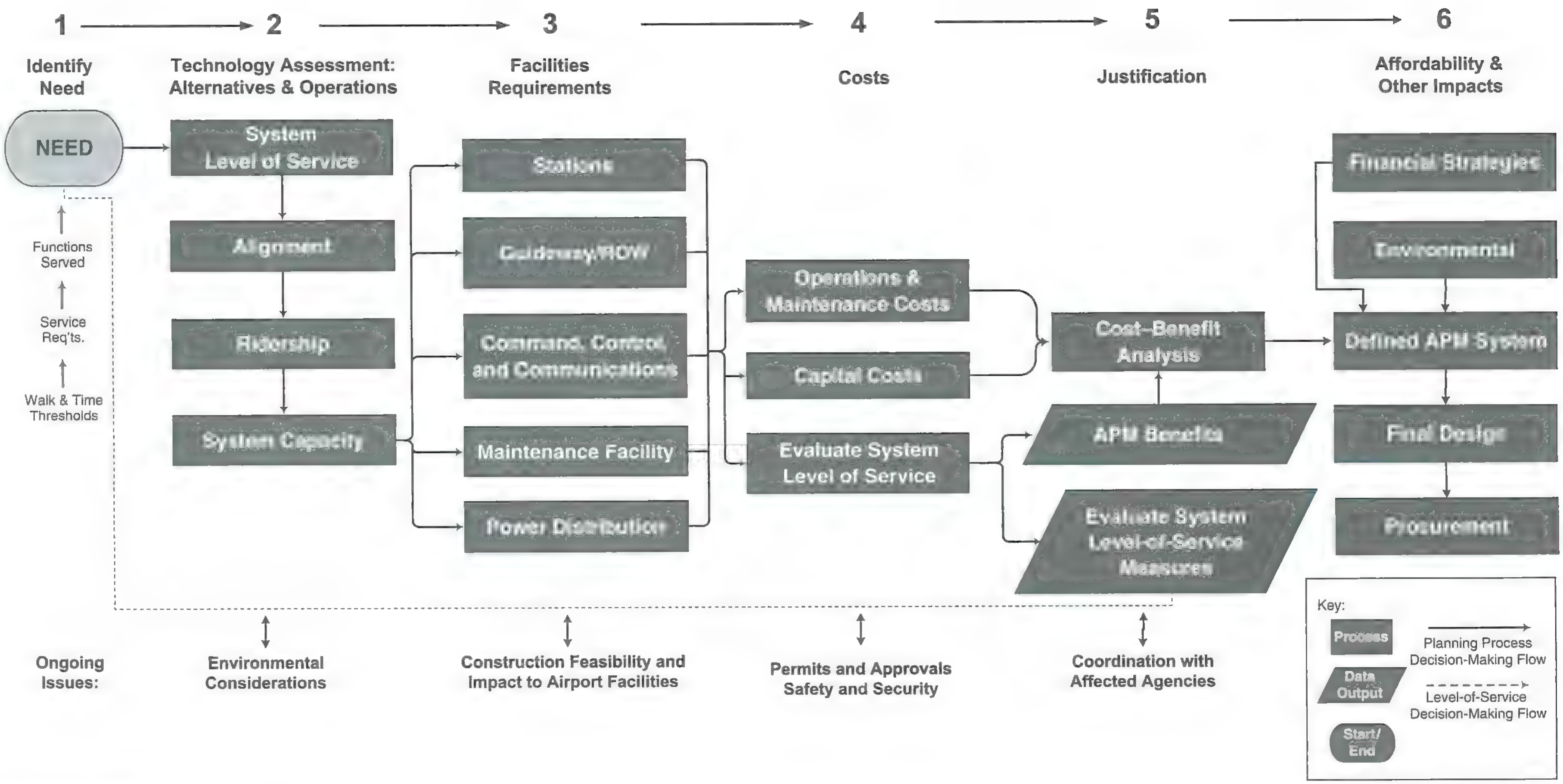
Assuming that these ongoing project requirements are met and project approvals are obtained during the preferred APM alternative definition, then there are still a number of issues to be addressed in establishing overall project feasibility. These issues deal with the following questions:

- Is the APM project justified?
- Is the APM project affordable?
- Is the APM project's environmental impact acceptable?

These final issues in the APM planning process are addressed in the subsequent sections of this chapter.

9.2 Cost–Benefit Analysis

Developing a robust justification for an APM system is an important and challenging exercise that takes into account the system's costs and benefits. This section is intended to be introductory to this topic and is not a detailed guide to cost–benefit analysis since numerous literature exists on the topic in general and for transportation in particular. Quantitatively estimating the cost side of a justification analysis is possible using the information developed in step 4 of the APM planning process (see Figure 9-1). However, quantifying the benefit side of the comparison is more difficult and varies by airport. Understanding the specific airport's goals and objectives is the key to quantifying benefits. The benefits are often



Source: Lea+Elliott, Inc.

Figure 9-1. General APM planning process.

a function of the APM's level of service (improved frequency, shorter connect times, etc.) that will have been identified in steps 2 through 4 of the APM planning process.

Benefits from an APM system accrue to the riders in the form of time savings. Estimating ridership time savings involves placing a value on the time of each class of rider. These same time-saving benefits accrue to airports through more efficient throughput, whether it is the landside or airside of the facility.

Landside APMs reduce O&D parking demand and airport roadway congestion, and under certain configurations can enable the airport to process more transfer passengers between terminals. The benefits for the general public are in the form of reduced noise, reduced air pollution, and improved visual appearance, as well as other, more intangible factors. Public benefits such as reduced noise and air pollution, and intangible factors such as appearance, should be estimated.

Airside APMs allow airports to operate with a significantly larger number of gates, thereby enhancing inter- and intra-terminal throughput capacities. In this case, an APM may be the only way an airport can achieve its desired growth (number of gates), and rather than a cost/benefit comparison, it becomes an affordability issue.

Whether a landside or airside APM system, all benefits and costs affecting the aviation public or attributed to the airport must be considered and evaluated in the analysis. This includes monetary gains (e.g., lower operating costs) and reductions in non-monetary elements (e.g., travel time, environmental impacts).

9.2.1 Approach and Methodology

The FAA has developed a document entitled *FAA Airport Benefit–Cost Analysis Guidance* for use under its Airport Improvement Program (AIP). Its stated purpose is to provide clear and thorough guidance to airport sponsors on the conduct of project-level benefit–cost analysis (BCA) for capacity-related airport projects. Under the AIP, airport capacity projects meeting a threshold of $5 million or more in discretionary grant funding over the life of the project must be shown to have total discounted benefits that exceed total discounted costs. While this guidance document outlines the critical areas of concern and the methodologies required to conduct a comprehensive BCA, airport sponsors are also encouraged to make use of innovative methods for quantifying benefits and costs where these methods can be shown to yield superior measures of project merit.

The FAA document outlines a multi-step process for conducting a proper cost–benefit analysis. The steps are as follows:

- Define project objectives;
- Specify assumptions about future airport conditions;
- Identify the base case (no investment scenario);
- Identify and screen all reasonable alternatives to meet objectives;
- Determine appropriate evaluation period;
- Establish reasonable level of effort for analysis;
- Identify, quantify, and evaluate benefits and costs of alternatives relative to base case;
- Measure impact of alternatives on airport use;
- Compare benefits and costs of alternatives;
- Evaluate variability of cost–benefit estimates;
- Perform distributional assessment when warranted; and
- Make recommendation of best course of action.

TCRP Report 78: Estimating the Benefits and Costs of Public Transit Projects is another excellent reference on this topic. That report is written as a guidebook to practitioners as well.

9.2.2 Landside versus Airside Considerations

Landside Considerations

As discussed in the FAA document, efficient landside access to airports is vital to the perceived utility of air transportation. Access projects such as a landside APM may yield important benefits. These benefits may reduce landside delays for passengers, meeters/greeters, cargo shippers, and airport/airline employees attempting to access the airport by automobile, bus, taxi, or rail.

Efficient landside access benefits passengers, meeters/greeters, and cargo shippers because of reduced transit and vehicle hours resulting from less time spent in congested conditions. Passengers, meeters/greeters, cargo shippers, and airport/airline employees may also be able to schedule travel time more efficiently because they no longer have to allow time for airport road or parking congestion. Landside congestion may also be alleviated if passengers were able to arrive closer to departure times. Other potential benefits include reduced automobile emissions (due to fewer automobiles and trucks tied up in congested conditions), improved safety (for persons in vehicles and airport pedestrians), and lower operating and maintenance costs (due to less employee time spent in congestion while traveling on the airport grounds).

Airside Considerations

An important part of any cost–benefit exercise is to categorize the impacts (the costs and benefits) of the passenger conveyance options under consideration. An airside APM provides the airport with benefits from efficient inter- and intra-terminal conveyance that overcomes excessive walk distances and provides easy access between and within passenger

terminal facilities. In some cases, such systems may eliminate the need for vertical conveyance such as elevators and escalators and facilitate the use of wheelchairs and passenger assist vehicles. An airside APM also improves throughput by accommodating luggage and minimizing the effects of personal space preferences by passengers.

Summary

The specifics of the analysis vary somewhat between airside APMs and landside APMs. In spite of these differences, the general steps of an airside or landside APM cost–benefit analysis are similar and can be summarized as follows:

1. Describe the impacts (costs and benefits) applicable to each system user/stakeholder, their relative importance, and the level of their measurement and evaluation;
2. Determine the ability to measure and monetize impacts and ensure against double counting;
3. Analyze and determine the applicable units for each of the impacts, and monetize when reasonable;
4. Convert the future monetary values of costs and benefits into present value and sum the two to estimate a net value;
5. Quantify (or if not quantifiable, list and describe) the non-monetized impacts; and
6. Combine the monetized and non-monetized impacts into a summary evaluation matrix with each impact given a relative weight or priority.

9.2.3 The Value of Time in Passenger Transportation

While estimating the cost side of a cost–benefit comparison is relatively straightforward, the benefit side can, in many cases, be complicated. The analysis of both landside and airside access and circulation necessitates the assessment of delayed benefits. Such benefits can be calculated by determining the value of travel-time savings. Values can be calculated by conducting analyses based on the costs contained in the FAA's Office of Aviation Policy and Plans bulletin entitled *Treatment of Value of Passenger Time in Economic Analysis.* The treatment in this document is based on long-standing research on air passenger travel. The basic findings are as follows:

- Given the distance traveled and the price of time, a theoretical model predicts the logical passenger choice among air, rail, and bus transportation.
- Business travelers behave as if their price of time is approximately equal to their hourly earnings; the price of time of personal travelers appears to be considerably lower.
- The value of time to an individual may vary not only with the purpose of the trip, but may also with its length, time of day, and other factors.
- Moreover, the value of time saved in travel may be different for different individuals even when hourly earnings are identical.
- The application of these techniques and estimates to specific problems requires additional empirical information relevant to the particular problem under study.

The cost–benefit analysis methodology suggested for both ground access and inter- and intra-terminal access projects in the FAA guidance document calls for the quantification of delay reduction. This is accomplished by comparing modes. Landside quantification occurs through the use of automobile traffic simulation models, where the analysis considers capacity and peak factors while focusing on vehicle and passenger volumes. Airside quantification occurs through the use of queuing models to simulate reductions in delays incurred by passengers moving through terminals.

9.2.4 Cost Estimates Impact on the Project Feasibility

Although planning cost estimates are intended primarily to compare the relative cost differences among the various alternatives, it is important to realize that airport executives may use early cost estimates to establish an order-of-magnitude range for the cost of the project. Early cost estimates are often used by airport officials to determine an upper threshold for project approval.

The ultimate goal of the planning process is to provide an executive-level summary of the system requirements, various alternatives, resulting costs, and major issues to be considered in the APM planning process. For this reason, it is appropriate to develop one or more budgetary cost estimates to establish an accurate range of costs as part of the alternative analysis process.

Prior to developing any planning cost estimates, airport planners and their cost estimators should become very familiar with the entire budget development process. Although many of the cost drivers will not affect the alternative analysis process, each of these elements should be evaluated with respect to the impact on the decision-making process. O&M cost estimates are one of the most important APM planning analyses since an inaccurate estimate can have significant repercussions. It is recommended that the estimate be compared with current O&M costs for existing airport APMs that are similar in nature.

9.3 Funding and Finance

The APM system capital and O&M costs will have been estimated in step 4 of the planning process. A funding analysis determines if these costs are affordable. Airport APM sys-

tems are typically publicly owned and financed. As a result, the airport's APM financing strategies involve one or more of the commonly used public financing tools. This section presents an overview of factors and potential funding sources for airport planners to consider in developing financing strategies for the implementation of an airport APM system.

9.3.1 Potential Funding Sources

The following are sources of funding typically used by airport operators in the United States to finance large capital projects, including APM systems. These funding sources could be applied individually or in combination to fund an airport APM system.

Airport Improvement Program—The FAA administers the AIP program, which provides grant assistance to public-use airports for capital improvements that enhance safety, capacity, security, or the environment.

Passenger Facility Charges (PFCs)—PFCs are part of a federal program administered by the FAA in which airport operators apply for authorization to collect and use PFCs to fund eligible projects. The FAA summarizes: "The Passenger Facility Charge Program allows the collection of PFC fees up to $4.50 for every enplaned passenger at commercial airports controlled by public agencies. Airports use these fees to fund FAA-approved projects that enhance safety, security, or capacity; reduce noise; or increase air carrier competition."

Applications to the FAA for the use of PFC funds to build APM systems on the landside of the airport have seen limitations enforced by FAA when the APM system extends to facilities that are off airport property. The FAA has strictly interpreted the intent of PFC use to be limited to serving only airport users, and primarily air passengers.

When capacity of the landside is an issue and APM systems can serve to increase the capacity by connecting with off-airport transportation facilities, then FAA has been willing to consider partially funding the system and facilities with PFCs (subject to assurances from the airport that the APM ridership will primarily comprise air passengers). Examples of PFC-funded landside APM systems are those with off-airport extensions that connect the terminals with nearby intermodal transit stations at airports, such as New York–JFK, Newark–EWR, Miami International (future), and Phoenix (future). Other examples of airport APM systems that extend off of airport property and that have been built using PFC funding are those that connect to a consolidated rental car facility. Examples of this type of functional connection are Atlanta and Miami (future).

If the connection between the off-airport station is such that only airport users would ride the APM system between the airport terminals, the landside facilities, and the remote station, then use of PFC has been approved by FAA, but typically at a reduced level compared to strictly on-airport projects.

Airport-generated revenues—Airports generate revenues from various sources, including airline landing fees, vehicle parking, rental car and terminal concession operators, off-airport commercial vehicle access fees, and customer facility charges (CFCs) from users of rental car facilities.

Airport revenue bonds—Proceeds from the sale of revenue bonds are the most common form of financing used by airport operators for large capital improvement projects.

Other forms of finance—Other, less common, forms of finance available for airport projects are general obligation bonds backed by local tax revenues, special facility bonds backed by commitments from facility users, and commercial paper.

Public–private partnership (P3)—P3s (or PPPs) are a growing method of implementing transportation infrastructure in which a private venture will typically finance, design, build, and operate/maintain a facility or system in exchange for a guaranteed revenue stream and/or development rights from the public entity to cover debt service and other costs.

Real estate development and value enhancement—Landside airport APMs can positively affect the value (sales price, rental rates, etc.) of commercial property at the airport. Value enhancement can come in terms of improving connection time/ease between parking and terminals, or in terms of linking airport property to the regional rail system.

9.3.2 Financing Strategy Considerations

Airport APM systems are typically publicly owned and financed. As a result, the airport's APM financing strategies involve one or more of the commonly used public financing tools. The following are factors to consider in aligning the sources described above to develop a financing strategy for an airport APM system.

Structure of the project and AIP and PFC eligibility—Airside and landside APMs that operate exclusively within airport boundaries and carry only airport users have generally been eligible for FAA AIP and/or PFC funding.

Airline agreements—Many operating agreements between airlines and airport operators include provisions whereby certain airport expenditures, including use of airport revenues on capital improvements, require approval by a majority of the airlines signatory to the agreement.

Landside APM systems linking to revenue generating facilities—An option in cases where landside APM systems link terminals with parking and rental car facilities is to apply a portion of the revenue generated by these facilities to cover the debt service or O&M costs for an APM system, particularly if the APM replaces a shuttle bus operation.

Multi-tiered debt structure—Interest rates and debt coverage requirements can vary for different forms of finance (debt coverage or ratio of revenue to annual debt service).

Project phasing—In cases where funds are limited but the need is great, the airport operator may consider implementing the minimum operable segment of an APM system (the one that provides the greatest benefits from a level-of-service perspective and/or is the most feasible from a cost and financial point of view), postponing the remainder of the planned APM system. This requires a good system staging plan and will increase the costs of each segment and the overall system.

9.4 Environmental Impacts

9.4.1 Environmental Considerations

At this point in the planning process, the APM has been defined to the appropriate level so that the subsequent cost estimates and funding analysis has shown the APM to be affordable. Another issue that must be considered at this point is whether the environmental impact is acceptable. The design, construction, and operation of APMs is not covered in detail in environmental guidance by the FAA, FTA, or Federal Highway Administration (FHWA), and as such falls under different regulatory jurisdictions depending on the design and implementation of the system, maintenance facilities, and power distribution systems. The construction of on- and off-site facilities usually dictates which guidance to follow; however, the same elements are necessary to document regardless of the approving agency. FAA Orders 1050 and 5050 provide guidance on the type and extent of analysis required for the various categories of environmental impacts.

In the United States, some states are very active in the environmental review and permitting of airport development projects; other states are not. Some states have a National Environmental Policy Act (NEPA)-like review, which mirrors but is not exactly the same as the federal process. Some have no NEPA-like reviews, but do have state requirements and/or permits covering certain types of impacts (e.g., air quality, water quality, coastal resources, and state-listed endangered and threatened species). State environmental reviews can add complexity and time to the overall environmental review process. It is FAA policy and practice to combine federal and state environmental reviews to the extent possible in an environmental impact statement (EIS), or at least to have the reviews running concurrently rather than sequentially.

On-Site Considerations

When constructing an APM within the confines of the airport, the environmental considerations become a part of the larger environmental document prepared for the airport. Still, there are several considerations that will need to be documented in order for all elements of the APM to be accurately considered during the NEPA mandated process. If the APM system is constructed outside of the purview of a larger airport environmental document, such as an EIS, then the governing agency may require an environmental assessment (EA) or supplemental EISs, or they may simply state that the facility will qualify for a categorical exclusion (CE), depending on the scope of construction. Each of these environmental options will be decided on an individual basis; however, the FAA is fairly specific on when a CE can be filed and since on-site APMs typically are constructed on land that has already been improved (beyond the natural condition), CEs are a likely first step for APM construction and expansion.

CEs are prepared when a proposed action meets the definition contained in 40 CFR 1508.4, and, based on past experience, does not involve significant environmental impacts. These actions are ones that:

- Do not induce significant impacts to planned growth or land use for the area;
- Do not require the relocation of significant numbers of people;
- Do not have a significant impact on any natural, cultural, recreational, historic, or other resource;
- Do not involve significant air, noise, or water quality impacts;
- Do not have significant impacts on travel patterns; and
- Do not otherwise, either individually or cumulatively, have any significant environmental impacts.

Any action that normally would be classified as a CE but could involve unusual circumstances will require the federal agency, in cooperation with the applicant, to conduct appropriate environmental studies to determine if the CE classification is proper. Such unusual circumstances include:

- Significant environmental impacts;
- Substantial controversy on environmental grounds;
- Significant impact on properties protected by Section 4(f) of the DOT Act or section 106 of the National Historic Preservation Act; or
- Inconsistencies with any federal, state, or local law, requirement, or administrative determination relating to the environmental aspects of the action.

Off-Site Considerations

The FTA has recognized APMs constructed to access off-site areas as a technology option that would fall under its purview for approval of environmental documentation. While the sponsoring agency for the specific project may be the FAA, the FTA will likely act in a reviewing capacity for APMs that are constructed to access off-site locations. Additionally, the construction of off-site APMs introduces a new realm of environmental consideration that may not have been previously examined, and as such a more detailed environmental analysis may be warranted.

The application of a categorical exclusion becomes less likely as off-site improvements occur, given the introduction of additional sensitive receptors and potentially sensitive environmental areas. In addition, the noise levels for non-rubber-tire vehicles will begin to warrant analysis. An environmental assessment will likely be necessary for off-site APM construction unless the system is being linked to another mode of transit. If the APM is acting as an extension of another mode of transit, a supplemental EIS will likely be necessary.

Information regarding the mapping of sensitive receptors and conducting noise and vibration impact analyses, as well as on the policies regarding the FTA acting in a review capacity, can be found in the FTA/FHWA joint guidance on environmental impacts. It is likely that the passage of future surface transportation authorization bills will require further clarifications for off-site impact analyses that will be available at the FTA website. Coordination efforts between FAA and FTA will be required throughout the process of analyzing any proposed off-site improvements. Additionally, the FTA has made a noise impact calculator available to determine the distance of impact for various vehicle technologies, which will help in determining the distance requirements for mapping sensitive receptors.

9.4.2 Environmental Assessments for APMs

When the significance of impacts of a transportation project proposal is uncertain, an EA is prepared to assist in making this determination. An EA requires analysis and documentation similar to an EIS, but with less detail and coordination. Depending on whether certain environmental thresholds of significance are exceeded, an EA will either lead to a finding of no significant impact (FONSI) or a requirement for the preparation of an EIS. If it is found that significant impacts will result, the preparation of an EIS should commence immediately.

In the case where the APM system is being planned for landside applications, especially when it will impact an off-airport community or when federal funds are used, the project may be subject to NEPA regulations. If so, the project may require preparation of an EIS and the obtaining of a record of decision (ROD) from the EPA. Alternatively, the project may not require a full EIS to be prepared, but only an environmental assessment. Either way, these issues must be addressed in order to guarantee the ultimate feasibility of the project.

9.4.3 Preparation of an Environmental Assessment

The outline and content of an EA must conform to the requirements established in the Council on Environmental Quality (CEQ) regulations and the requirements of FAA Order 5050.4A. It is assumed that airport planners are well versed in the preparation of an EA; therefore, only APM-related issues are covered here. Key sections of the EA will include:

Alternatives—This section discusses the alternatives developed as part of the environmental analysis, reviews the criteria used in the alternative evaluation, and identifies the alternatives eliminated from detailed consideration.

Affected environment—This section provides a discussion of the environmental setting of the airport, discusses the current status of the airport facilities, and reviews the criteria to be used in the detailed analysis of the remaining alternatives (in the environmental consequences section).

Environmental consequences—This section compares the environmental impacts of each reasonable alternative (identified under the alternatives section) in addition to the no-action alternative. This section considers the following environmental impacts:

- Noise;
- Compatible land use;
- Social impacts;
- Induced socioeconomic impacts;
- Air quality;
- Water quality;
- Soils and geology;
- DOT, Section 4(f) Lands;
- Historic, architectural, archeological, and cultural resources;
- Biotic communities;
- Endangered and threatened species;
- Wetlands;
- Floodplains;
- Coastal zone management programs;
- Coastal barriers;
- Wild and scenic rivers;
- Farmlands;
- Energy supply and natural resources;
- Light emissions;
- Solid waste disposal;
- Sanitary waste; and
- Hazardous waste.

Mitigation—This section summarizes any necessary mitigation options considered and the proposed mitigation plan for the preferred alternative. Additionally, the documentation of construction-related mitigation strategies will be essential for APM facilities since elevated structures will have higher noise and vibration impacts during the construction phase. The construction phase impacts, while not permanent, could be the largest impacts for APM projects.

On- and Off-Site Impact Analyses

The geographic scope of the project will determine the government agencies that will have a role in the approval of an EA or EIS conducted for APMs. For on-site improvements utilizing only FAA funds, the FAA will likely be the sponsoring and reviewing agency. For on-site improvements where operating funds may come from an FTA or FHWA revenue source, they may desire to be a reviewing agency for on-site improvements; in such cases, coordination of the reviewing agencies will be a critical component of the environmental documentation process.

Off-site improvements will likely require the involvement of at least the FAA and FTA; the FHWA may want to review as well, based on the nature of the project and the impacts to any federal-aid roads within the area. The United States Department of Transportation (U.S. DOT) has drafted regulating language for conducting environmental analyses across multiple agencies and in conjunction with NEPA requirements (23 CFR Part 771, Environmental Impact and Related Procedures). This guidance illustrates inter-agency review procedures and defines the roles that each agency plays when reviewing another agency's sponsored project. This guidance provides the best example of the flow of information during environmental reviews across multiple agencies to aid in completing a supplemental EIS for projects that intersect another FTA- or FHWA-sponsored project.

CHAPTER 10

APM System Procurement

The APM system has been properly defined (Chapter 8), and a final check on feasibility has been performed (Chapter 9). The resulting project is now ready to be procured (see step 6 of the chart in Figure 10-1). In this chapter, post-planning procurement activities are described. For each of these steps there are decisions to be made by the airport regarding options within the procurement, implementation, and operations phases of the project.

This chapter defines the typical airport APM procurement contracting approaches and procurement processes. The contracting approach is the way the work is divided into packages (contracts) that best suit the nature of the project and the parties expected to carry it out. The procurement methodology is the procedure used to select the team that will do the work defined in the contract approach. *TCRP Report 131: A Guidebook for the Evaluation of Project Delivery Methods* is an excellent resource on this topic.

10.1 Contracting Approach

The contracting approach is the way the work is packaged in contracts that best suit the nature of the project and the parties expected to carry it out. The work of an APM project can best be divided into two general areas:

Operating system—The operating system includes all of the mechanical and electrical equipment that make up the APM system (vehicles, automatic train control system, communications systems, power distribution system, station equipment, guideway equipment, safety equipment, other equipment, and the maintenance equipment and tools).

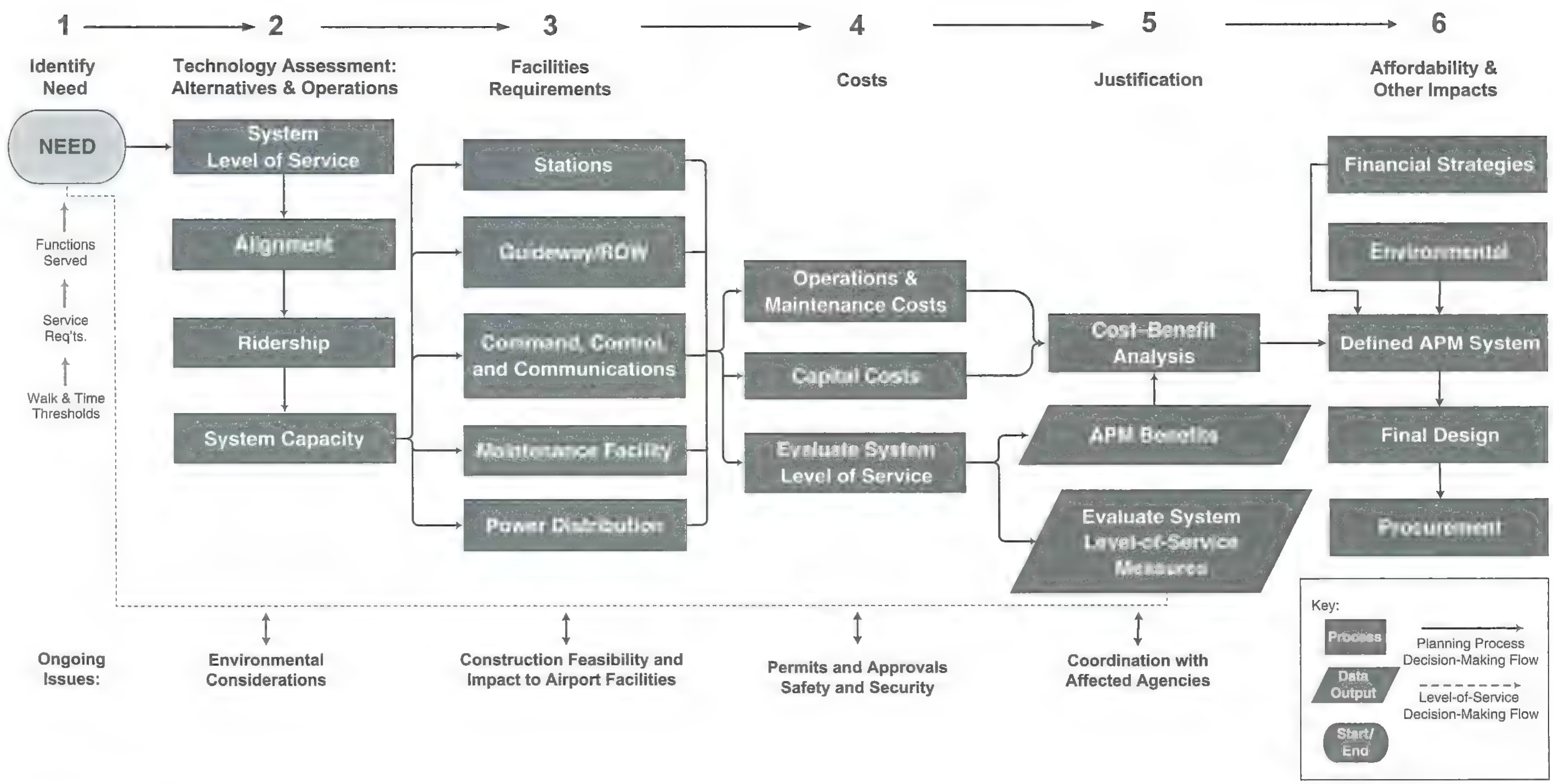
Fixed facilities—Fixed facilities are the buildings, spaces within buildings, building mechanical and electrical systems, guideway structures, stations, power substations, and other structures and civil works associated with and in support of the APM.

Assigning the work should be based on "who does what the best" and "who can best control the risks" of that part of the project. The operating systems of APMs are typically proprietary, often with patented designs, and are usually available only as unique complete packages. Therefore, it is best that at least the operating system be delivered through a single contract with a qualified supplier.

Minimizing interfaces, conflicts, and contractor dependencies should be among the deciding factors in assigning the work of the fixed facilities. Facility work that is not involved with other construction (such as concourses and other airside facilities) and that is related only to the APM can be packaged with the operating system or designed and built separately. Having different contractors working in the same spaces can create conflicts. Where there are interfaces between the work of separate contractors, they will be dependent on each other for the correctness of the interfaces and the schedule. Such conflicts, disagreements over interfaces, and schedule delays can lead to claims being filed by the contractors and an increase in costs. More contracts mean more airport coordination and management effort and increased risks associated with managing and controlling the interfaces.

Typically the APM system supplier is not familiar with or qualified to design and construct the APM facilities, although the supplier must provide system–facility interface information during both the design and construction phases. Many airport APMs are integrated into terminal buildings and other facilities. Further, the airport management typically wants to control the design and construction of the system to fit into the overall plan and design of the airport/facilities and not interfere with airport operations. This will affect the approach taken to procure and implement the APM. Often the APM project is separated into two or more contracts: one for the operating APM system and one or more for the facilities (which are often part of a larger facility project).

The airport rarely wants to operate and maintain an actual train system. An APM, like other airport electromechanical



Source: Lea+Elliott, Inc.

Figure 10-1. General APM planning process.

systems, is seen as another tool that provides the requisite level of service to airport users. The APM system supplier is perceived as the organization that best knows the system, including its O&M. Additionally, the airport usually wants to ensure that the system operates as required for a significant period of time, particularly as it is proprietary and the detailed design and implementation is usually done by the supplier, with any problems being solved by the supplier. Finally, if the procurement process includes pricing an O&M period, the airport can receive a competitive package for the system and its O&M. Thus, most airports have opted to have the system supplier perform all O&M services for at least several years. Three to 5 years is typical, and usually the contract is renewable for at least one more term at the airport's option. Subsequent periods are often negotiated, but occasionally they are competed among the supplier and third parties. Variations on this include the airport staff overseeing the operations and the supplier performing maintenance. A few airports do both or have contracted with a third party for both or for maintenance, usually after an initial period undertaken by the supplier.

10.2 Procurement Methodology

A number of different procurement methodologies have been used for airport-related APM systems since 1971. Typical procurement alternatives include:

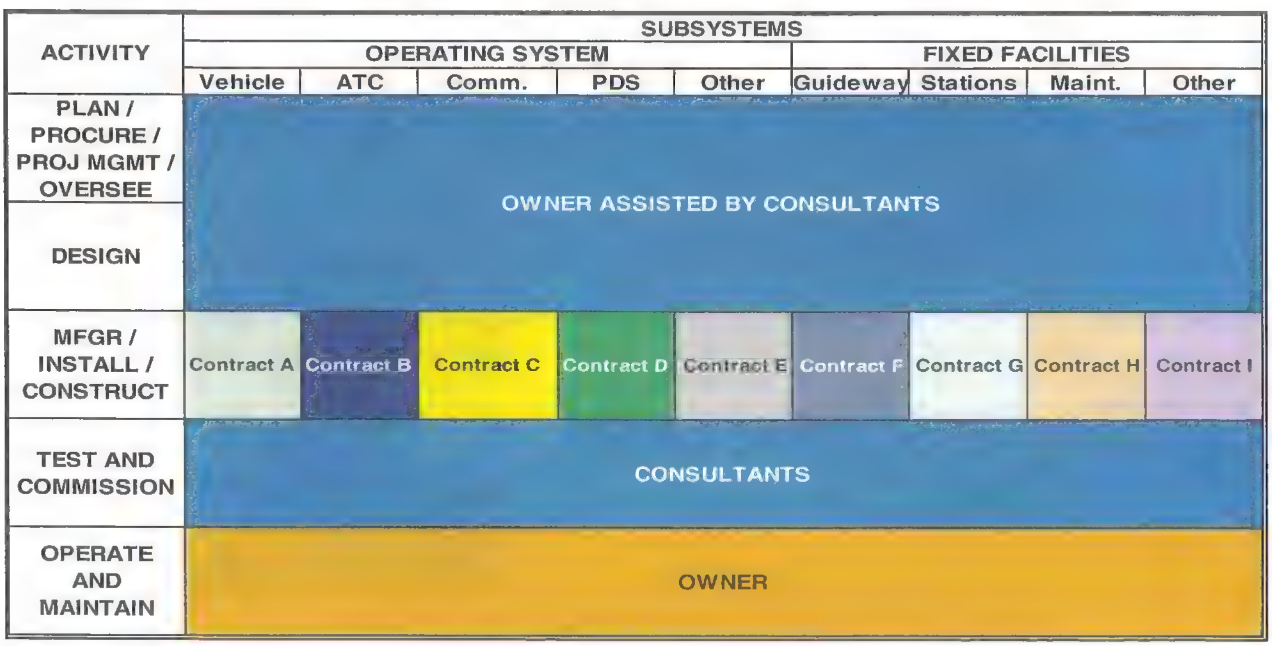
- Design-bid-build
- Limited design-build
- Split design-build
- Design build
- Design-build-operate-maintain

These broad categories are discussed in the subsequent subsections. There can be variations to each approach; only the basic procurement concept is discussed in these subsections.

10.2.1 Conventional Design-Bid-Build

DBB is the conventional project procurement approach under which the airport contracts separately with a designer(s) and construction contractor(s). The design entity provides detailed, prescriptive design (plans and specifications) documents. The airport subsequently solicits fixed price bids from construction contractors to perform the work provided in the design documents. The contractor is usually selected on the basis of lowest price. The airport and design entities may separate the project design documents into multiple specialty contracts. Figure 10.2.1 depicts this approach with each aspect of the system and facilities undertaken by a separate contractor.

This approach requires the airport to award and administer separate contracts to each contractor. This alternative allows the airport to retain maximum design control, but the airport also has the responsibility and risk for designs, contractor coordination, integration, and scheduling. The airport would need a large staff or set of consultants for detailed design, contract administration, and project/construction management to assume the responsibility for these multiple contracts. It would



Source: Lea+Elliott, Inc.

Figure 10.2.1-1. Design-bid-build project approach.

be responsible for the cost, schedule, and technical risks of the project as well as the integration and interfaces among the many contracts. With such a separation of project aspects, the airport usually undertakes the O&M functions as well.

This approach is often followed for urban rail transit projects, but rarely, if ever, is used for airport APMs.

10.2.2 Limited Design-Build

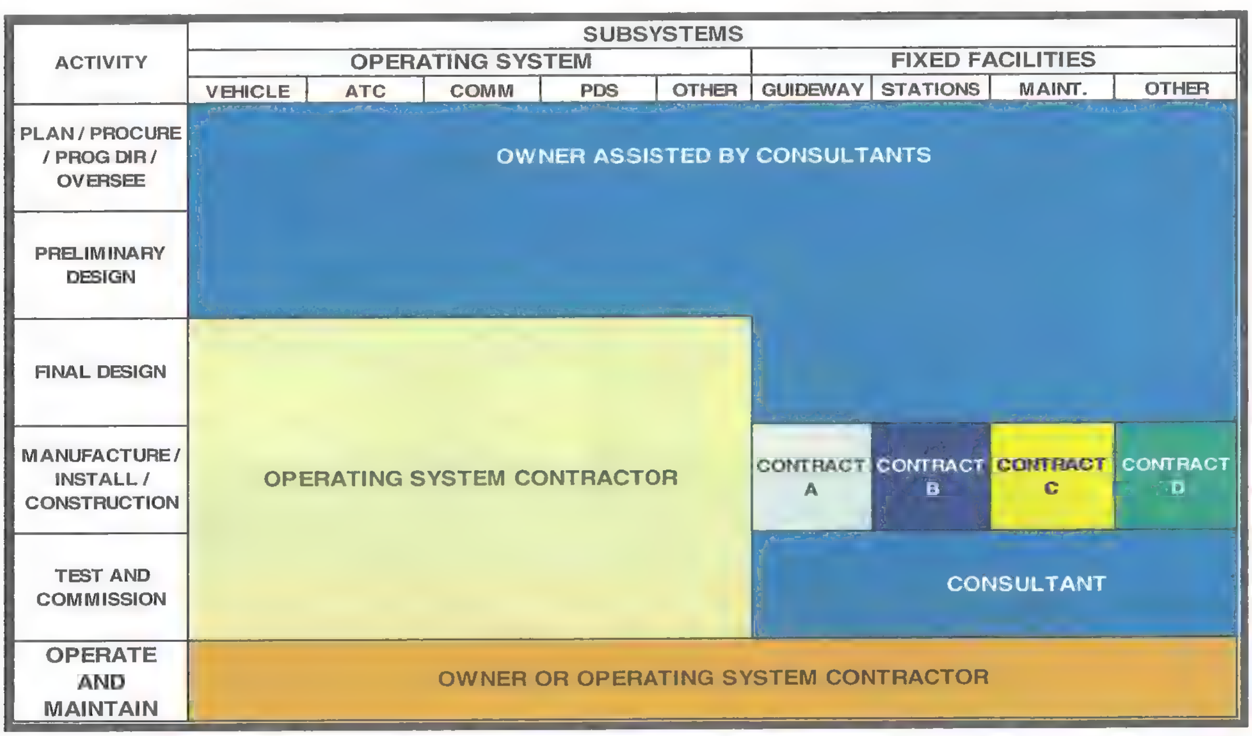
With a limited design-build (sometimes called limited turnkey) project approach, the airport and its system consultant develop performance specifications for the system elements, usually as a complete system. The airport and its architectural and engineering consultants develop detailed design plans and specifications for the facilities. The airport then contracts with a single entity to perform all APM operating system design, manufacture, implementation, and tests under a single design-build contract. The facilities are each designed, procured, and built separately using the conventional design-bid-build method. See Figure 10.2.2-1. This alternative allows the airport to retain facility design control, but transfers most of the system integration responsibility to the APM contractor, except possibly for the interfaces among the operating system and facilities. Interfaces can be led by the airport and its system and project management consultants, or this responsibility can be assigned contractually to the APM contractor. This is the approach taken by most U.S. airports for their APM projects. Usually the APM contractor is also given an extendable 5-year O&M contract to prove the system, as discussed earlier.

10.2.3 Split Design-Build

The split design-build (sometimes called split turnkey) approach is the same as the limited turnkey alternative with respect to the operating system. However, with this approach, all the APM facilities are contracted to a single entity that will perform all final design and construction under a second design-build contract. This consolidates all facilities' design and construction into a single point of contact. This is shown in Figure 10.2.3-1. This approach is often taken when the APM is entirely within a terminal project and the APM facilities are undertaken by the terminal construction contractor. This alternative transfers most of the integration to the contractors and limits much of the airport's risk. The airport can retain the responsibility for integration of the operating system and facilities, which are usually done with the assistance of its system and project management consultants, or the responsibility can be assigned to the system or facilities contractor.

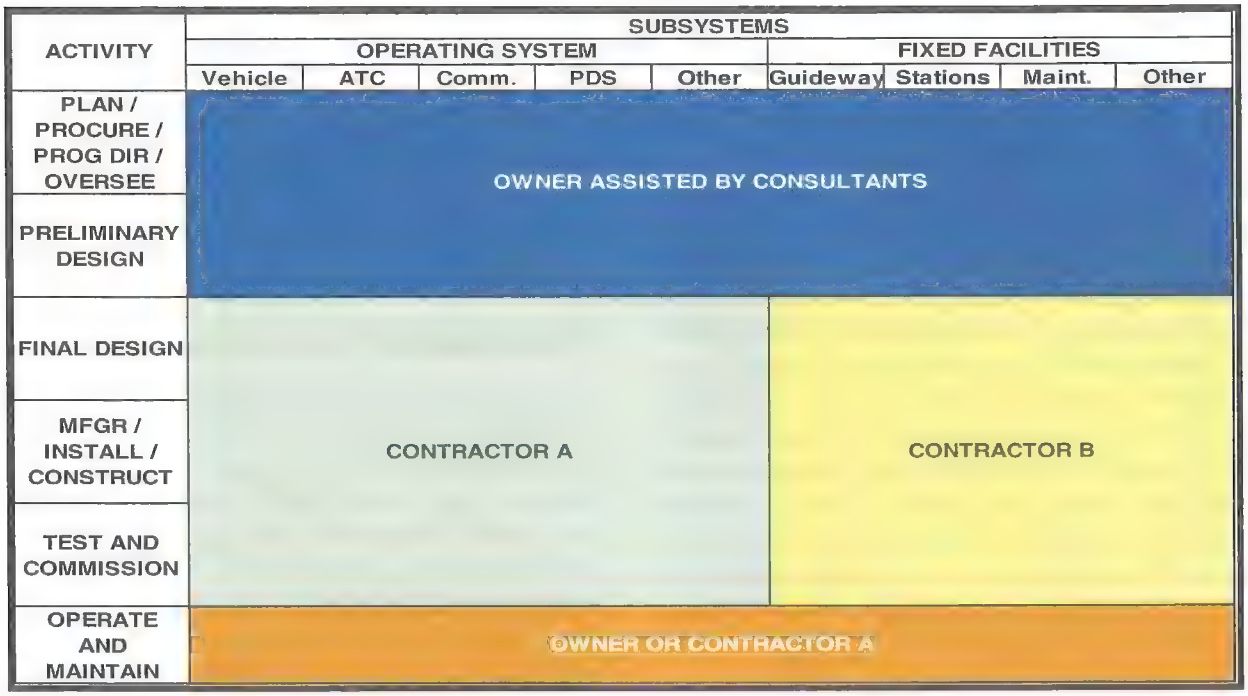
10.2.4 Design-Build

The DB approach, sometimes called a turnkey approach, allows the airport the maximum opportunity to reduce costs and schedule risks by contracting with a single entity for design and construction of the entire project, for both system and facilities. With this alternative, the contractor assumes responsibility for all the detailed design, construction, integration, schedule, and cost risks, and the airport has one organization to go to, as shown in Figure 10.2.4-1.



Source: Lea+Elliott, Inc.

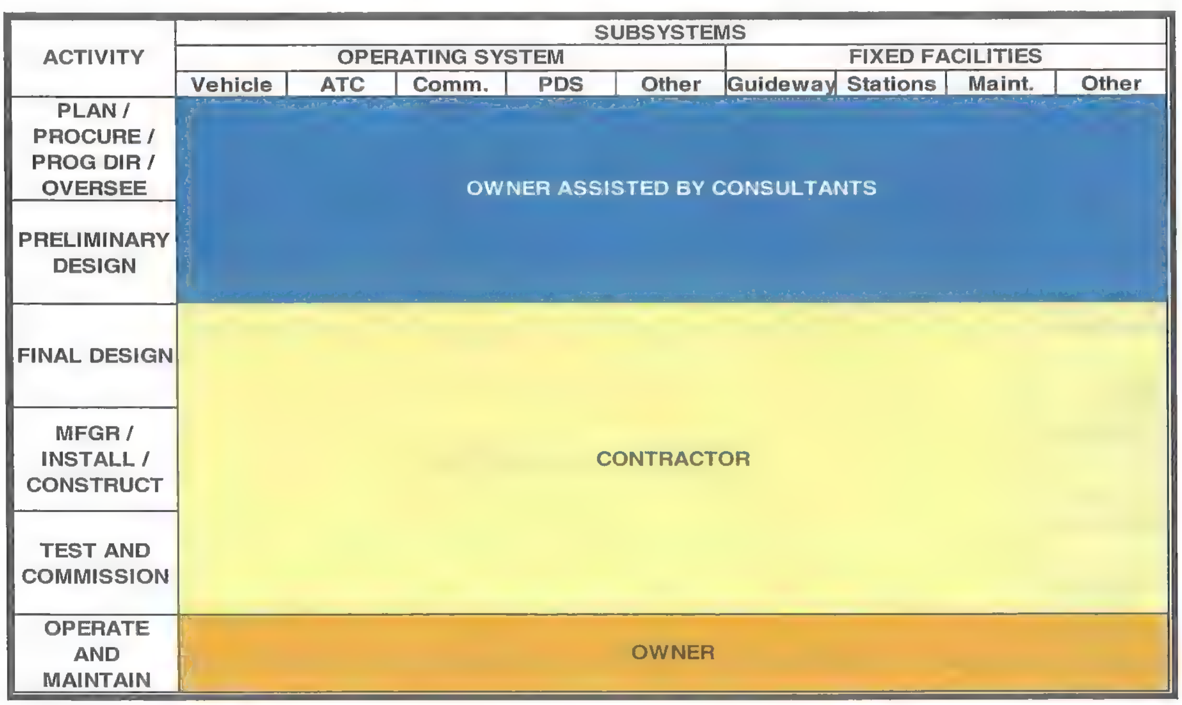
Figure 10.2.2-1. Limited design-build approach.



Source: Lea+Elliott, Inc.

Figure 10.2.3-1. Split design-build approach.

The single procurement and internalized project integration can result in a shorter overall schedule. The airport has a large, consolidated package for procurement. The airport and its system and facility design team take the design to about the 30% level, enough to define the project thoroughly and obtain valid prices. The airport subsequently loses some control of the detailed design and construction packaging and implementation. It will want to retain some design and schedule control over the project due to airport operational needs; this is possible with proper use of design reviews and payment milestones and the use of an overall project management team.



Source: Lea+Elliott, Inc.

Figure 10.2.4-1. Design-build approach.

Because no single contractor has all the needed expertise in APM systems and facilities, the airport selects a team with all of the requisite capabilities. Particularly if a low-bid process is used, the winning team might not include the best APM technology, the best designers, and the best construction contractors. To obtain the best of each category, the airport could procure each major contractor separately and then require that the separate winning contractors form a team. This approach has the potential problem of contractors that are not compatible, and thus increases the airport's risks and integration responsibilities, partly negating the possible advantages of having a single team. With this approach, the contractor team leader is often the construction contractor because it has the bonding and management capabilities. The airport or a third party would have O&M responsibilities. Construction and design contractors typically want to do their work, be paid, and move on; they do not want to retain longer-term responsibilities such as for O&M. If the system is supplied by an APM supplier, it could be retained to provide O&M services.

10.2.5 Design-Build-Operate-Maintain

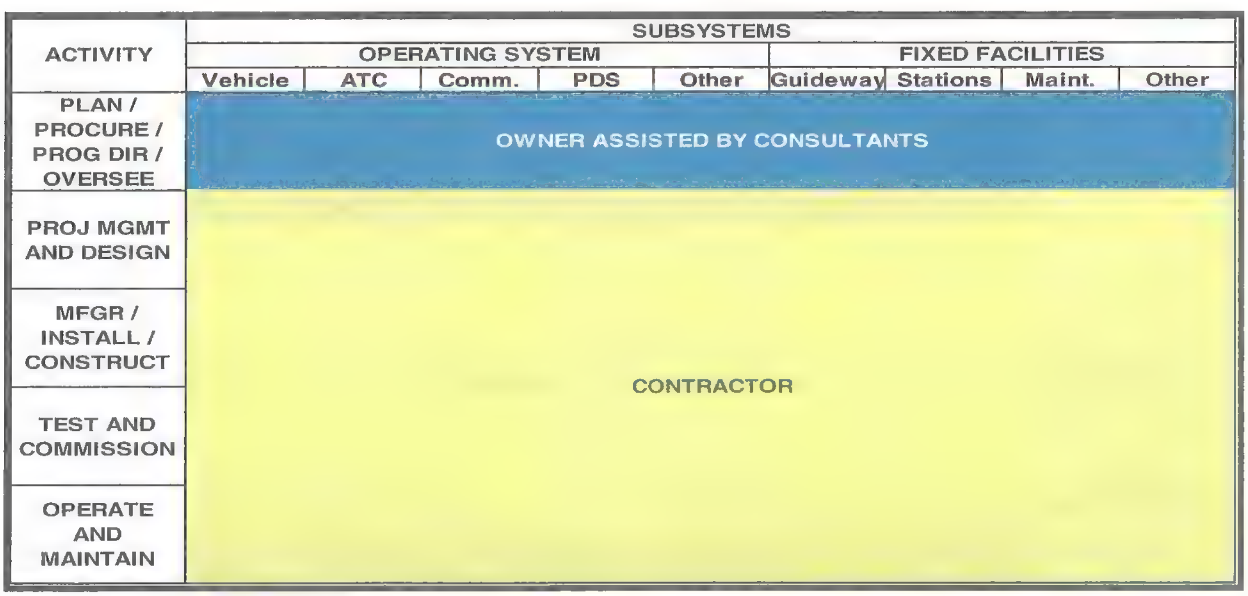
The DBOM (sometimes called super turnkey) approach transfers the operations and maintenance of the system to the contractor in addition to the design and construction of the operating system and facilities. See Figure 10.2.5-1. The advantage to the airport is that the contractor will be responsible for all aspects of the APM design and construction, as well as the operations and maintenance of the system. Typically, however, the O&M contract will be with the system supplier and not the entire contractor team. See the discussion in the previous section. A possible advantage of this approach is that the schedule for procurement and construction might be reduced.

The airport gives up considerable control of all aspects of the project. This makes the contractual and procurement documents and phases critical to the success of the project.

A variation of the DBOM approach is where the airport operates the APM system while the contractor maintains the system. This approach is abbreviated as DB-M.

10.2.6 Public-Private Partnership

In the past several years, this approach, also called P3 (or in FTA parlance, Penta-P), has become more prevalent in the United States. At least one airport-related APM project, the Bay Area Rapid Transit (BART) Oakland Airport Connector, considered this approach. This is an airport access project with an APM connecting the BART rapid rail Coliseum Station with the terminals at the Oakland International Airport. BART was the lead agency, although the airport had a major role. This approach was similar to the DBOM/super turnkey approach but with a mix of public and private funding. The public agencies control the project in terms of procurement, general design (approximately 30%), environmental clearances, jurisdictional coordination, project oversight, and approximately half of the construction cost. Because some of the capital funding was from the FTA, its rules and processes governed overall. However, because of the airport aspects, FAA and other requirements typical of an airport project also were applicable. The P3 team was led by a financial organization and included an APM supplier, facilities designer, project manager, and construction contractor. The financial organization would pro-



Source: Lea+Elliott, Inc.

Figure 10.2.5-1. Design-build-operate-maintain approach.

Table 10.3-1. U.S. airport procurement approaches.

PROJECT	YEAR OPEN	CONTRACTING METHOD		COMMENT
		System	Facilities	
Tampa	1971	DB-M	DBB	Airport does O (operations)
Seattle	1973	DB	DBB	Airport does O&M
D/FW Airtrans	1974	DBOM	DB	Changed to airport does O&M
Atlanta	1980	DBOM	DBB	
Miami	1980	DB-M	DBB	Airport does O; Changed to 3rd party
Houston – Tunnel	1981	DBOM	DBB	Changed to 3rd party
Orlando	1981	DB-M	DBB	Airport does O (operations)
Las Vegas	1985	DBOM	DBB	
D/FW Tr A Am	1991	DBB	DBB	
Tampa Extension	1991	DB-M	DBB	Airport does O (operations)
Tampa Garage	1991	DBOM	DBB	
Pittsburgh	1992	DBOM	DBB	
Chicago O'Hare	1993	DBOM	DB/DBB	APM supplier responsible for guideway & MSF; O&M changed to 3rd party
Cincinnati	1994	DBOM	DBB	
Denver	1995	DBOM	DBB	
Newark	1996	DBOM	DB/DBB	APM supplier responsible for guideway; airport for stations & MSF
Houston – Elevated	1999	DBOM	DBB	O&M changed to 3rd party
Newark Extension	2000	DBOM	DB/DBB	APM supplier responsible for guideway; airport for station
Minneapolis RAC	2001	DBOM	DBB	O&M changed to 3rd party
Detroit	2001	DBOM	DBB	
Minneapolis Green	2002	DBOM	DB/DBB	APM supplier responsible for guideway; airport for stations & MSF; O&M changed to 3rd party
San Francisco	2002	DBOM	DBB	
New York JFK	2002	DBOM	DB	APM supplier responsible for guideway; airport for stations & MSF
Tampa Airside E	2002	DB-M	DBB	Airport does O (operations)
D/FW Skylink	2005	DB-M	DBB	Airport does O (operations)
Houston Extension	2004 & 2010	DBOM		O&M changed to 3rd party
Miami North Terminal	2005	DBOM		
Atlanta CONRAC	2009	DBOM	DB/DBB	Construction contractor leads DB team (with APM supplier) responsible for guideway & MSF; airport for stations
Dulles	2010	DBOM	DBB	
Las Vegas Terminal 3	2011	DBOM	DBB	
Miami – MIAMover	2011 est.	DBOM	DB	Full DBOM; construction contractor leads DB team (with APM supplier) facilities
Sacramento	2012 est.	DBOM	DBB	
Oakland Airport Connector	2013 est.	DBOM	DB	DBOM to P3 to DBOM; full DBOM; contractor responsible for system & facilities

Source: Lea+Elliott, Inc.

vide the other part of the capital funding. It would be repaid, including interest, through the O&M payments of the airport over a 35-year concession period. Ultimately this approach was abandoned in favor of the full DBOM approach for many reasons, including problems in the financial markets in 2009 and lack of competing P3 teams.

This approach may be considered for other airport APM projects if the required funding is not initially available and other conditions are conducive. It is, however, only an alternate funding mechanism.

10.3 Airport APM Procurement Approaches

Procurement approaches used by U.S. airports for APM projects are summarized in this section to help the reader understand what has been done elsewhere. Table 10.3-1 lists APM projects undertaken since 1971 and the procurement approach used for each. The majority used a limited design-build or limited design-build-operate-maintain approach for the APM operating system. These approaches are favored

because they give the airport control over the design and construction of projects in or near the terminals and airport airside while continuing airport operations. It is usually more efficient and cost-effective to have the system supplier operate and maintain the APM, particularly at the high reliability and service levels necessary for an airport APM.

In a few cases, the airport has assumed the operation and maintenance after the supplier quit the job or performed an initial operate-maintain term to verify the design through operation. While Section 10.2 described four different procurement approaches, there are in fact a number of additional approaches that are possible given the different entities and areas of responsibility.

10.4 Procurement Process Alternatives

This section discusses two procurement process alternatives: sole source and competitive.

10.4.1 Sole Source Procurement

In a non-competitive, sole-source procurement, the airport determines that only one supplier is capable of or is strongly preferred for the delivery of the APM system. State and local statutes/ordinances usually permit agencies to make this determination if they can demonstrate that a sole-source procurement is in the best interest of the project (due to existing conditions, budget, and/or schedule) and that a competitive procurement process would not yield any greater benefits. In such a case, the airport enters into negotiations with the selected supplier, and when the contractual terms, scope of work, and price are agreed, a contract is awarded. Usually this is used for an extension to an existing system that the selected APM supplier installed initially, and due to the proprietary nature of the APM, no other supplier can do the work.

In almost all cases when the APM will be newly built and is not an expansion or addition to an existing system, there are multiple technologies that can provide the required service. Thus a sole-source procurement is not justified, and a competitive procurement approach should be pursued.

10.4.2 Competitive Procurement

Many different competitive procurement processes have been used successfully for public procurements of APM systems. Three basic types are:

- Competitive one-step
- Competitive two-step (low bid)
- Competitive negotiated procurement (best value)

These types are explained in the following subsections. There are many variations involving these approaches. The exact procedure should be developed in compliance with the airport's customary contracting and procurement procedures and applicable laws and regulations.

In all of these, an airport can first use a request for information/interest (RFI) to determine the potential APM suppliers that might participate in the procurement. Typically the RFI will include a summary description of the project (initial and ultimate), and a list of information requested, such as general information about the supplier's technology(ies), specific technical solutions with the supplier's technology for the project, experience with similar projects, financial capabilities and strengths, project management approaches and tools, and the like. This can be the initial formal step of a procurement or an informal seeking of information. As part of the formal process, there will also be information about screening criteria to select a shorter list for the next step in the process. In this case, some suppliers that express interest might be removed from consideration, either because they and/or their technology did not meet project requirements or they did not respond to the RFI. The RFI should be sent to all known APM suppliers and advertised in trade journals and other media that will reach the widest audience. Typically this is a two- to three-month-long step, depending on the administrative and legal requirements of the airport.

The next step (or possibly first step) in the process can be a request for qualifications (RFQ). This is always a part of the formal procurement process. It is used to pre-screen potential proposers and technologies to focus the list to a set of well-qualified ones. The RFQ contains the same sort of information and response requirements as an RFI. This formal pre-qualification process can save the airport the time and expense of evaluating proposals from unqualified proposers/technologies, as well as saving prospective proposers who are not qualified the cost of preparing a proposal. Because the RFQ is an additional step, it normally extends the length of the procurement process by several months. Alternately, the airport can go directly to the proposal stage without any such screening.

If an RFI or RFQ is not used, then the airport should notify all known APM suppliers and give the RFP extensive advertising/publicity.

Competitive One-Step

The competitive one-step procurement approach is characterized by a solicitation by the airport to which potential contractors submit their qualifications (if no RFQ) and technical, management, commercial, and price proposals all at one time. The RFP is developed in detail by the airport and its consultant. This package includes everything the proposers need to submit a complete and responsive proposal:

1. The instructions to proposers (which includes summary evaluation criteria as well as a list of everything required to be included in the proposal);
2. A detailed description of the project (plans and drawings to the 30% design level);
3. The contract;
4. General terms and conditions [often standard for the airport, but modified for a design-build type (DB, DB-M, DBOM, etc.) contract];
5. Special (management) provisions;
6. Technical provisions (performance specifications);
7. O&M provisions (often a separate O&M contract); and
8. Project reference drawings.

The RFP specifies precisely the information required in the proposal. Typically these instructions and the format are detailed so that the airport can clearly compare and evaluate each proposal against the criteria and against other proposals.

The airport evaluates the responses using a detailed evaluation plan, which is important in order to avoid or defend against challenges to the selection. The evaluation plan includes detailed evaluation criteria (and weightings as appropriate) and is established in advance. The criteria normally include such items as demonstrated successful experience in designing, implementing, and operating systems similar to the project; evidence that equipment is technically mature and capable of satisfying the availability and other performance requirements; compliance with provisions in the contract; corporate resources sufficient to back up performance guarantees and warranties; demonstrated ability to complete projects of similar size and complexity on time and within budget; experience and capabilities of key personnel; aesthetic compatibility and physical and structural fit of the system in the provided facilities; and ability to accomplish future expansion.

Based on the evaluation and comparison of proposals, the airport makes a determination on responsibility and responsiveness and then selects the lowest price or best value (rare; see subsequent discussion) proposer for contract award. This approach is best suited for a clearly defined project with a set of prescriptive design specifications. This approach is appropriate for APM facilities. However, given that APM systems are proprietary and designed by the supplier to meet performance specifications, it is less applicable to APM systems.

At any point in any of these processes, the airport may decide to award the contract, cancel the procurement, or re-advertise the procurement.

Competitive Two-Step

The competitive two-step procurement approach can be used when the potential suppliers or their products or services being solicited might not be considered equal in terms of technical merit, quality, or price.

Step one. This step consists of a partial RFP being sent to the list of potential proposers. The partial RFP includes all aspects of a full RFP except for pricing. (Any pricing data will typically disqualify a proposal in step one.) The technical, management, and qualifications information are then evaluated in accordance with the evaluation plan to determine the acceptability and ranking of the proposers. There can be one or more iterations for clarification questions, with updated proposals being submitted by each proposer. Addendums to the RFP can be issued; final, conformed proposals are submitted and evaluated. The final, complete proposal must be in conformance with the RFP, including all clarifications and addenda. Final non-priced proposals are categorized as either qualified or not qualified for price proposals.

At the end of this (single or iterative) step, proposers deemed by the airport to be qualified for the project are invited to participate in step two. Those proposers found to be not qualified will be notified of the reason(s) for this determination and will not be permitted to proceed further.

Step two. Upon successful completion of step one, an invitation to submit price proposals will be issued to those firms whose step one proposals have been qualified (the competitive range). This could be all or a few of the step one proposals. Typically, two or three proposals are wanted in the competitive range.

The airport then evaluates the price proposals, again based on the evaluation plan, which includes reasonableness. If a low-price approach is used and the competitive range has been judged in step one to be essentially equal, then the airport selects the proposer submitting the lowest total fixed-price bid for the APM procurement and the APM O&M contract. If there are options included in the RFP, the prices for these options can also be included, but the selected options should be determined in advance.

If a best-value approach is used, then the weighted scores from step one and the step two proposals are summed and the proposer with the highest score is selected. The best-value approach considers price and other factors to arrive at the proposer that offers the best overall value to the airport. The evaluation criteria must be clear, as must the process to arrive at the final score. There are multiple ways of doing this given in the literature. One that has been used successfully in several airport APM procurements is based on a numerical approach. Each evaluation criterion is disaggregated into a number of specific categories or requirements. Each is weighted. Numerical ratings are given to each proposer on each item (typically a 5-scale: 0, 1, 2, 3, 4), depending on whether and how well the item is met. The ratings and weightings are applied to technical, management, qualification, and price aspects of the proposal. The sum of these ratings and weightings is then used to select the best value proposal.

Again, at any point in the process, the airport may decide to award the contract, cancel the procurement, or re-advertise the procurement.

Competitive Negotiated Procurement

The competitive negotiated procurement approach is a method whereby the contract award is made on the basis of price and other evaluation factors that are considered to be in the best interest of the airport. The airport has the ability to negotiate with multiple proposers at the same time in strict confidence on all matters in the proposals.

In the approach, the airport solicits proposals via the RFP process. The respondents are required to submit their qualifications and technical, management, and price proposals at the same time but in separate envelopes. No cost, price, or financial information is to be included in the technical or management proposals. Initial evaluations of these proposals are completed without knowledge of price and financial data in order to ensure that such evaluations are objective and free from any low-price bias. Proposers and proposals are rated and ranked based on these non-price proposals, by either a quantitative or qualitative procedure.

After opening the price proposals, in confidence, the airport evaluates them; then, in conjunction with the technical, management, and qualifications parts of the proposals, it determines the competitive range. The airport can then conduct separate negotiations on technical, management, pricing, and other matters, in strict confidence with each of the suppliers with proposals found to be in the competitive range.

Upon completion of negotiations, the airport requests best and final offers (BAFOs). The BAFO follows the same format as the initial proposals and can include updates on any or all aspects of the proposal requested by the airport. BAFOs are evaluated in accordance with the same criteria and procedures as the initial proposal. The best-value award is made on the basis of price and other evaluation factors that are considered to be in the best interest of the airport. As with the other approaches, at any point in the process, the airport may decide to award the contract, cancel the procurement, or re-advertise the procurement, including using a different approach.

The term "bid" is not used in the competitive negotiated procurement method. The acceptability and quality of a proposal is assessed in terms of a set of requirements and evaluation criteria. Most competitive negotiated procurements score the qualifications of the suppliers as part of the basis for the award. Even with a best-value approach, price is usually considered the key evaluation factor because it is the determinant of project affordability and proposal value.

Before soliciting proposals, the airport must determine whether to evaluate the responsive proposals on the basis of the lowest price or to score them using predetermined criteria to identify the best overall value to the airport. The best value may be based on a predetermined weighted combination of the price, technical merit, management, qualifications, and/or commercial scores or a ranking.

CHAPTER 11

Operations and Maintenance

In planning for the implementation of an airport APM, there are alternative O&M approaches that should be considered. The purpose of this chapter is to present the possible O&M approaches for airport APMs and to identify their advantages and disadvantages. It is important to note that the optimal O&M approach for an airport when opening an APM may be different than it would be after the APM has been operating for a number of years. Some of the unique issues for ongoing O&M services are also presented in the chapter. The research produced from ACRP Project 03-07, "A Guidebook for Measuring Performance of Automated People Mover Systems at Airports," should be a useful reference on this topic.

11.1 Initial O&M Approaches

APMs have been operated and maintained at major airports for almost 40 years and at over 40 different airports. Based on this experience, four candidate approaches to initial O&M are identified, along with their advantages and disadvantages.

11.1.1 APM Supplier O&M

O&M responsibilities are assigned to the APM equipment supplier. This is the most common approach to APM system O&M at airports. The supplier typically hires the vast majority of its staff locally. The selection of the winning supplier is based, at least in part, on the combined implementation cost and O&M costs for some period of time, typically for 5 years. This contract structure encourages the supplier to perform life-cycle cost analysis since both capital and O&M costs are considered in the selection. Furthermore, the supplier's O&M payments are based on achieving performance levels defined in the contract. In this approach, the airport awards a single contract for the implementation and O&M of the APM system. Linking the O&M services with the initial capital construction provides a powerful incentive for the supplier to provide its best efforts on both fronts. Typically, the cost of the O&M services is included in the supplier's proposal, with the combined capital and O&M costs constituting the basis of award. After contract award, most airports have executed two separate contracts for capital construction and O&M services, respectively.

Advantages:

- APM supplier is intimately familiar with the APM operating system technical features and has direct access to the technology's replacement parts and materials.
- APM supplier has access to lessons learned from other similar APM installations.
- No O&M staff administrative responsibilities for airport.
- Payment to APM supplier is based on system performance, with incentives for surpassing the system availability goal and penalties for not achieving the goal. This incentive is typically passed on to all of the supplier's employees, creating a highly motivated workforce.

Disadvantages:

- Profit is the APM supplier's primary concern.
- May be more expensive hiring APM supplier personnel than hiring airport personnel.
- APM supplier may need to be monitored.

11.1.2 APM Supplier Initial O&M

O&M responsibilities are assigned to the APM supplier for a short initial period. This initial period may be one to 2 years, compared to a 5-year period of typical DBOM contracts. Prior to transitioning out, the supplier trains the airport staff, and they become responsible for O&M activities. A support person from the APM supplier is typically retained as a subcontractor to the airport. This approach offers the ability to defer training of airport staff prior to APM operations.

Advantages:

- Passenger service is the airport's primary objective.
- Airport may retrain and use employees who are displaced by the APM system as O&M personnel (if APM is replacing bus operation).
- Airport has in-depth, first-hand knowledge of the APM system performance problems and can act in the best interest of the airport operation.

Disadvantages:

- Airport must hire and train O&M staff.
- Airport must provide the administrative services (payroll, benefits, etc.) for the O&M work crew.
- Airport will not have continued access to the lessons learned.
- Airport's work crew may not be as knowledgeable about the APM system's technical features as the APM supplier's personnel.
- Financial incentives and penalties may be more difficult to implement.

11.1.3 Airport O&M

O&M responsibilities are assigned to airport staff at the beginning of passenger service. The supplier provides training to the airport staff prior to system opening. This approach is similar to the approach in section 11.1.2 (APM Supplier Initial O&M), except that airport staff begins O&M activities immediately with the opening of the system.

Advantages:

- Passenger service is the airport's primary objective.
- Over time, the airport may retrain and use employees who are displaced by the APM system as O&M personnel (if APM is replacing bus operation).
- Airport will achieve in-depth, first-hand knowledge about the APM system's performance problems and can act in the best interest of the airport operation.

Disadvantages:

- Airport must hire and train O&M staff.
- Airport must provide the administrative services (payroll, benefits, etc.) for the O&M work crew.
- Airport will not have any access to the lessons learned.
- Financial incentives and penalties may be more difficult to implement.

11.1.4 Third-Party O&M

O&M responsibilities are assigned to a third-party contractor. This is similar to the approach in section 11.1.1 (APM Supplier O&M), except that the O&M contract is completely separate from the procurement and is open to all qualified firms. This approach is not significantly different from the APM supplier O&M approach in terms of phasing or impact on the airport APM's existing staff, but costs may be slightly higher. Two examples of third-party O&M are Houston Airside and Chicago Landside.

Advantages:

- No O&M staff administrative responsibilities.
- Payment to third-party contractor is based on system performance, with incentives for surpassing the system availability goal and penalties for not achieving the goal.

Disadvantages:

- Profit is the third-party contractor's primary concern.
- Third-party contractor will not have any access to the lessons learned, nor will technical support be available from APM supplier organization or from the APM supplier's other O&M applications.

11.2 Initial O&M Period Versus Future O&M Periods

The potential O&M options and their advantages/disadvantages for a new APM system are typically different than the options for an existing APM system that is coming to the end of an existing O&M contract. The competitive environment is typically strong for the initial O&M contract because multiple APM suppliers compete to both construct (design and build) and operate/maintain the APM system. Suppliers are judged in an open competition in terms of price and qualifications. For the four O&M approaches listed above, the first two approaches (with the APM supplier providing initial O&M services) have clear advantages, while the third (airport O&M) and fourth (third-party O&M) have more clear challenges.

The environment for the renewal of O&M services for an existing APM system is much less competitive than for an initial system. The established APM supplier has its equipment in place and has a unique understanding of its technology in general, as well as its specific application at that airport. The current supplier also has access to the technology-specific parts and materials. This combined knowledge and materials advantage of the existing supplier makes it difficult for airport staff or a third-party provider to compete against an existing APM supplier for providing O&M services.

11.3 Competitive Procurement of Ongoing O&M Services

Competitive procurement of the ongoing O&M services of an operating APM system is a recent phenomenon. Although the airport APM industry is approximately 40 years old, most examples of competitive procurement of O&M services have

occurred since 2005. One example is so recent that its outcome in terms of pros and cons cannot yet be fully ascertained.

To date, the sole reason for competitive procurement of O&M services for APM systems appears to be the airport's desire to ensure the lowest cost for the services. In no example of competitive procurement was there a problem with the technical performance of the original O&M provider. Nor have there been examples of the existing cost of the O&M services being considered (by the airport) to be exorbitantly high. Despite corporate philosophies of retaining the O&M services for their original product, in only one case of competition has the original APM supplier been successful in retaining the O&M services. In this example, the original supplier was again selected through a best-value evaluation but not primarily by price.

Historically, ongoing O&M services have not been competitively procured. One reason is probably that the APM industry is highly specialized, with each supplier's system being proprietary in nature. Thus, there has historically been no established competitive market for APM O&M services, and the universe of responsible third parties capable of providing such services remains very limited despite the recent solicitations. It is generally thought that the acceptable performance of the original O&M providers and their long-term relationship with the airports simply served the best interests of the airport and the airport's customers—airline passengers. The strong and consistent APM system performance outweighed the potential lower cost.

Five examples of competing APM O&M services are provided below. The first example is unique because it is not recent in terms of the previously noted 4-year time frame. Due to the sensitive nature of these examples, neither the airport nor the O&M provider are mentioned by name.

1. **Small Landside APM at Large Airport**
   - APM supplier ceased supporting this system approximately 25 years ago.
   - A third-party O&M provider (non-supplier) has been the sole O&M provider through multiple solicitations.
   - There have been no other known proposers.
2. **Large Airside APM at Large Airport**
   - Initially four proposers; two elevator proposers were found non-responsive.
   - The original APM supplier was selected (retained) based on a best-value evaluation, not lowest price.
3. **Large Airside APM at Large Airport**
   - Three proposers: original APM supplier, a third-party O&M provider, and a jetbridge maintainer.
   - The third-party O&M provider was selected based primarily on price, replacing the original APM supplier.
4. **Small Airside APM at Large Airport**
   - Two proposers; original APM supplier and a third-party O&M provider.
   - The third-party O&M provider was selected based primarily on price.
5. **Landside and Airside Systems at Large Airport**
   - Solicitation was a continuation of the previous contractual arrangement: a single O&M contract for both systems.
   - Three proposers: existing APM supplier, an outside APM supplier/operator, and an elevator company.
   - The outside APM supplier was selected based primarily on price.
   - The outside APM supplier hired most of the existing employees.

11.4 Summary of O&M Approaches

In terms of procuring O&M services for a new APM system, there is a clear advantage in contracting with the APM supplier for an initial O&M period. The linking of construction and operations helps ensure that the system performs as it is specified. The historically high level of competition among APM suppliers to construct new APM systems at airports has resulted in good O&M prices for the airport in the initial O&M phase.

The competitive environment for the ongoing provision of O&M services is quite different. With an operating APM system, the original APM supplier has a unique advantage over other potential O&M providers (airport, third party, other APM suppliers, etc.) in terms of technical knowledge, access to parts/materials, and access to skilled local labor.

Despite the inherent advantages of the incumbent APM supplier, introducing the element of competition for ongoing O&M services can provide the airport with some much-needed negotiating leverage. This will help ensure that the airport receives good value for its ongoing APM operations and maintenance. However, caution should be exercised if this approach is taken because, depending on the procurement method that is used, the airport may ultimately be forced to engage an O&M provider that is not its preferred choice.

CHAPTER 12

System Expansion and Overhaul

The focus of the guidebook to this point has been the planning and implementation of new APM systems at airports. This chapter focuses on existing APMs that need to be either expanded or overhauled. System expansion may range from (1) a simple increase in fleet size to (2) an extension of the guideway alignment, with new and/or lengthened stations, upgraded train control elements, and perhaps additional vehicles/trains. Similarly, an APM system overhaul can range from (1) a refurbishment of a single subsystem (i.e., station doors) to (2) a full replacement of multiple subsystems (vehicles, train control, switches, etc.).

The two typical passenger conveyance needs that require an increase in APM services are (1) an increase in passenger demand and (2) the introduction of new facilities to be served by the system. Thus, to differentiate meaning in the text, the following convention is used:

- **Fleet expansion**—The term "fleet expansion" is used to denote the addition of vehicles into the fleet and/or reconfiguring the fleet and associated system facilities to accommodate longer trains.
- **System extension**—The term "system extension" refers to a physical lengthening of the system, which involves all of the physical elements of the system (guideway, switches, stations, etc.) and may involve additional fleet.

12.1 APM System Expansion and Extension Planning

An important consideration in determining when an APM expansion is warranted is the performance of the existing fleet. The research produced from ACRP Project 03-07, "A Guidebook for Measuring Performance of Automated People Mover Systems at Airports," should be a useful reference on this topic. The need for expansion and/or extension of an APM system is driven by the same set of parameters that govern the need for a new APM system. These aspects are discussed in Chapters 5 and 6 of this guidebook.

Fleet Expansion

A fleet expansion is typically required by an increase in passenger demand on an existing APM system, necessitating an increase in system capacity. Capacity can be increased by increasing the frequency of trains (reducing headway) or by increasing the length of trains (vehicles per train), or by a combination of both. Assuming the system is operating at maximum capacity, in all of these cases the size of the fleet and the amount of fleet maintenance (and perhaps MSF size) will be increased.

System Extension

APM extensions involve adding more guideway to serve a new station or stations. Such extensions will necessarily include new guideway and associated wayside equipment (power rail, control elements, switches) as well as station equipment. Physical extensions of APM systems may involve adding vehicles, but this is not necessarily the case; it is possible that sufficient vehicles may be available in the existing fleet to serve the longer system. If not, new vehicles will have to be purchased. Finally, depending on the details of the extension, the MSF may need to be enlarged and/or relocated. The impacts of an APM fleet expansion or system extension on the different subsystems are depicted in Figure 12.1-1.

Whether an APM fleet expansion or a system extension is under consideration, the review of options and selection of the best approach is a multi-step process. The steps of this process are as follows:

1. Alternative development,
2. Alternative evaluation,

Requirements	Fleet	Station		MSF		Guideway	ATC	PDS
		Length	Number	Size	Site[1]			
Fleet Expansion								
Increased Freq.	●	○	○	●	○	○	○	◑
Longer Trains	●	●	○	●	○	○	○	◑
System Extension								
Same Capacity	●	○	●	●	◑	●	○	◑
Increased Capacity	●	●	●	●	◑	●	●	◑

Key: ● = Expand ◑ = Possible Expansion ○ = No Expansion

Note: [1] For the MSF site ● = change of site, ◑ = potential change of site, and ○ = no change of site.

Source: Lea+Elliott, Inc.

Figure 12.1-1. APM expansion/extension subsystem impacts.

3. Review of preferred alternative and comparison with no-build,
4. Development of the implementation plan, and
5. Decision making and appropriate approvals.

12.1.1 Planning for APM Fleet Expansion

An increase in the APM system capacity requirement necessitates a fleet expansion. The complexity of a project for fleet expansion depends on the type of expansion and the provisions that were made for such expansion in the original system. For example, the expansion could involve just adding a vehicle to existing trains. This could be a simple step if the stations and controls were originally sized to accommodate the longer trains, or it could be more complicated if no advance provisions were made. Further, adding additional vehicles could necessitate system changes and be quite involved, as when a shuttle system is modified to a pinched-loop system to allow more trains to operate.

When expanding the capacity of an existing APM, a comprehensive review and understanding of the existing system is critical. The following system characteristics should be available or gathered:

- Ridership,
- Peak period/non-peak period operations,
- Stakeholder concurrence and definition of acceptable impacts on level of service,
- Existing train length and designed ultimate train length,
- Existing facilities and their compatibility with the new larger fleet or increased train length, and
- Existing APM control and safety features (to evaluate any added requirements and upgrades that may be needed for the new train numbers and/or configuration).

The planning team for a fleet expansion project must understand the existing operational plan and must review and evaluate its potential degradation/interruption during the expansion work. By evaluation and analysis, a decision must be made regarding whether to subject the system to operational interruptions or to provide alternate means of transportation for passengers during expansion work activities. This becomes a tradeoff between impacts to passengers versus impacts to the schedule (and cost) of construction.

12.1.2 Planning Criteria Involved in Fleet Expansion

A number of APM facility and facility-related issues are critical and should be considered when planning a fleet expansion project involving more or longer trains. These facilities and issues are described below.

Station(s)—Determine if the existing station is ready for longer trains. Facility elements such as platform length, platform station doors, and dynamic signs must be evaluated. Additionally, the station platform size and layout must be analyzed to determine that it can handle additional passenger demand due to more frequent and/or larger trains. A NFPA analysis of passenger emergency egress from the station is typically required unless already provided and planned for in the original design.

Guideway—Typically, very few guideway changes are required if the fleet expansion involves only adding vehicles. If longer trains are involved, the system safe stopping distances and related control systems may require review and design level re-analysis. If the fleet expansion involves changing from a shuttle system to a pinched-loop system, new crossovers and switches will be required. This will require layout and placement of switches and crossover guideway, with appropriate rework in the guideway layout.

System equipment—For projects involving longer trains, the various subsystems involved with train movements must be analyzed to ensure that they can safely handle the longer trains; switches, power distribution, train

control, communications, and other similar subsystems must be investigated for adequacy.

Maintenance and storage facility—An MSF analysis should be made to confirm the need for additional MSF space to support a larger or reconfigured fleet. Also, the operational procedures in the MSF should be reviewed to determine if changes need to be made. Finally, in some cases fleet expansion may require additional MSF space.

Procurement—Fleet expansions are typically supported by the existing APM supplier under a sole-source contract. However, in some instances where the existing technology is obsolete, the original supplier has been engaged to replace the old technology with updated equipment. If this is the case, additional costs may be necessary to modify the system to accept the new technology.

Implementation—The airport planner involved with an APM expansion should have an understanding of the implementation issues associated with the project. This is important for planning the work and establishing a suitable project schedule and cost.

System testing period—A detailed test and acceptance period is required at the conclusion of any work affecting the configuration and/or operation of an APM system. This is necessary to ensure that passenger safety is not compromised. Therefore, adequate time for testing and verification of all work must be included when developing the total time for implementing the APM fleet expansion.

12.1.3 Planning for a System Extension

Some of the issues involved in planning the extension of an existing APM system are the same as for a fleet expansion. For example, data describing the existing system technical characteristics and operation must be available or gathered. See Section 12.1.1 for a list of such data.

In addition, other information and data related to the physical extension of the system needs to be available or developed; this information is critical to understanding the existing APM system and defining methods for accomplishing the extension work with minimal impact:

- Tie-in location(s). The tie-in location is where the new extension guideway will join the existing guideway. Any work in this area will impact the existing system and must be coordinated with day-to-day operation and maintenance activities.
- New area(s) to be served. A plan of the additional facilities to be served will facilitate layout of an appropriate guideway extension alignment.
- New station service locations. Within the new facilities, a determination of where service is desired.
- Characteristics of new passengers. Are the APM riders airline passengers? If so, what kind(s) of passengers are they, and what separation is required? Are employees involved? Must they be kept separate from passengers?

As with a planned fleet expansion, the planning team for a system extension project must understand the existing operational plan and must review and evaluate its potential degradation/interruption during the extension work. By evaluation and analysis, a decision must be made regarding whether to subject the system to operational interruptions or to provide alternate means of transportation for passengers during extension work activities. This becomes a tradeoff between impacts to passengers versus impacts to the schedule (and cost) of construction.

12.1.4 System Extension Configuration and Implementation

For an APM extension there are a number of facility and equipment issues that are critical and should be analyzed when planning the project. Many of the considerations are the same as for a fleet expansion; see Section 12.1.2. In addition, the following additional issues should be evaluated:

Vehicles—Analyses of the longer system's operation must be made to determine the additional number of vehicles that must be placed in the system to serve the additional stations and passengers. Consideration should also be given to the appropriate configuration of the trains; is the same train size sufficient, or are longer (or shorter) trains in order? Although such issues may be addressed manually, it is much better if a computer simulation of the complete new system can be made.

Station(s)—Station location and layout should be consistent with the rest of the system to ensure the passengers' uniformity of experience. Also, the new stations should be well-integrated into the facilities they serve. All of the wayfinding, size, and service issues identified for new stations in Chapter 8 should be addressed.

Guideway—The layout of the new system guideway is critical in developing a seamless and efficient connection between the existing system and new extension. The layout and the exact guideway geometry should consider multiple criteria, including location of the end of the existing system, the preferred location of the station(s) in the new facility, physical space and right-of-way for guideway alignment, and constructability and cost issues (aboveground or underground). For feasible guideway layouts, the evaluation should compare the one-time

cost of construction with the recurring costs of longer round-trip time, larger fleet, and higher power consumption for a sub-optimal alignment. Also see Chapter 8 for information related to planning new guideway alignments and layouts.

System equipment—For system extension projects, the various subsystems involved with train movements must be analyzed to ensure that they are still appropriate for both the old and new parts of the system. If new and/or longer trains are contemplated, then the pertinent subsystems must be analyzed relative to the new/longer trains to be sure that safety is not compromised; switches, power distribution, train control, communications, and other similar subsystems must be investigated for adequacy.

Maintenance and storage facility—An analysis should be made to establish the need for additional MSF space to support a larger fleet as well as to identify any changes in the maintenance function/procedures for the expanded system. The location of the existing MSF should be analyzed; an APM extension farther away from the MSF could impact the existing operational processes and efficiencies. These issues should be analyzed and additional MSF space/locations identified, if required.

Procurement—It is typically assumed that all extensions are supported by the existing APM supplier under a sole-source, negotiated contract. However, it should be noted that there are some cases where an extension project has involved a different operating system. A complete change of operating system (and supplier) typically requires additional capital costs to adapt the system to the new technology. These costs may be offset by the competitive aspects of procurement by bid rather than sole source.

Implementation—The airport planner involved with an APM system extension must have an understanding of the implementation issues associated with the project. This is important for planning the work and establishing a suitable project schedule and cost.

System testing period—A detailed test and acceptance period is required at the conclusion of any work affecting the configuration and/or operation of an APM system. This is necessary to ensure that passenger safety is not compromised. Therefore, adequate time for testing and verification of all work must be included when developing the total time for implementing the APM system extension.

12.2 APM System Overhaul

This section describes the planning and implementation issues associated with an APM system overhaul. APM system overhauls are sometimes referred to as refurbishments. For the purposes of this section, it is assumed that the APM to be overhauled is providing an essential function and cannot be shut down and must remain operational to provide passenger service for the duration of the work.

The information provided herein is intended to aid airport planners in planning APM overhaul projects. However, due to the proprietary nature and complexity of APM equipment, planning for modifications and overhaul of existing APM systems typically requires an in-depth knowledge of the equipment subsystems and their operation. For that reason, it is recommended that planning for APM system overhauls include input from knowledgeable system engineers.

The various subsystems that comprise an APM system have varying design lives, also known as useful lives. Such durations would typically be specified in the APM system's initial procurement. There are numerous factors that go into the development of a design-life duration for a given project. Therefore, a general listing of typical subsystem design-life durations with very specific numbers of years would not necessarily benefit the airport planner of an APM system overhaul.

Certain APM subsystems, such as central control and ATC subsystems, are sometimes replaced prior to the specified design life due to rapid innovations in control system technologies (e.g., microprocessor speeds). This innovation typically leads to an accelerated obsolescence, since it is generally more desirable to upgrade computer/microelectronics components with new technology than to repair old technology.

12.2.1 Identification of Needs and Constraints

The first step in planning for overhaul of an existing APM system is the identification of near-term, mid-term, and long-term system requirements. Typical planning considerations include future passenger demand, level-of-service, and budget considerations.

An additional major challenge in planning an overhaul is determining project constraints, including physical facilities, accessibility, operational, and so on. A major constraint may be the need to provide continuing passenger service. In this case, a determination must be made as to the acceptable level-of-service degradation that is permissible while the overhaul takes place. Typically the acceptable level of degradation is not a single value but varies throughout the day and may vary between seasons of the year. For example, there are typically nighttime hours when there is very little airport activity and when the APM can be completely shut down. In addition, many airports experience a seasonal peak when no degradation is acceptable, while some degradation of service is acceptable at other times of the year. These issues require significant airport input in the planning process. Another potentially significant project constraint may be the requirement to afford

non-overhaul work periods when system maintenance can be performed.

It is sometimes difficult to establish an acceptable level of degradation without also considering the associated costs for maintaining higher-order services. Typically the greatest cost is associated with the least degradation. Therefore, the level of degradation is one of the primary cost drivers that must be determined in planning system overhauls. Once the level of acceptable degradation is established, overhaul alternatives can then be explored.

The identification of post-project needs (goals) includes considerations of improvements to APM capacity, performance, level of service, reliability, efficiency, and aesthetics. The long-term need may be to expand the APM to new stations and/or eliminate obsolete or soon-to-be obsolete equipment. The constraints associated with these long-term needs include the airport's available budget (both capital and operations and maintenance) and coordination with other facility projects.

To verify the safety and operational reliability of an overhauled APM, significant testing will be required. Where system overhauls are conducted concurrently with other facility work, the conduct of system testing must be coordinated with other ongoing projects. During the construction phase of an APM extension, work areas can typically be shared between the APM contractor and other contractors. However, toward the completion of the APM overhaul, the system must be secured against all access by non-APM personnel so that operational testing can be conducted. This is a significant constraint that must be considered when coordinating with other related projects.

12.2.2 Overhaul Approaches

When considering an overhaul of an existing APM system, there are two primary approaches. The first approach involves replacing the existing technology with identical or next-generation versions of that technology. This approach is typically conducted by the same supplier as the original system. Also, this approach typically involves phased installation of the new equipment that is procured sole-source from the manufacturer.

The other primary approach is to replace the existing APM equipment with a new or significantly different technology. This can often best be accomplished by overlaying the new system equipment over the old, switching between the systems to facilitate continued passenger service, and installing, verifying, and commissioning the replacement equipment. Historically, the system overlay approach has typically been used for train control systems and vehicles. In such cases, the original equipment is used for passenger service, while the replacement equipment is installed and tested. At that point a switch-over is made, usually in a short period of time.

Subsystems such as the guideway, switches, power distribution, and station automatic doors are typically replaced using the phased installation approach, where one or more pieces of equipment are removed from service and a new component is then installed, tested, and commissioned.

Selection of Approach

The process for selecting the appropriate approach begins with the identification of the stakeholders. The group of stakeholders then considers the project objectives in light of the relative costs and impacts of the two approaches. The stakeholders develop the acceptable impacts to existing APM service compared to the cost of maintaining full APM system capacity throughout the project. An evaluation matrix can be used whereby weightings are assigned by the stakeholders to various project parameters such as cost, schedule, level of service, technical risk, and impacts to associated work. At one major airport, the stakeholders included representatives from the airlines. In this case, it was agreed that the best approach would be to select methods that minimized the impact to the APM passengers at the expense of extending the overall duration of the project and increasing the cost. Other airports have chosen to minimize the duration and cost of the project by accepting a greater degradation of APM service during the project.

Type of Procurement

In the first approach, phased implementation, equipment is usually procured through a sole-source negotiation with the existing system supplier. This is normally necessary because of the numerous proprietary interfaces between the various subsystem components. Also, the replacement equipment is typically provided by the system supplier because the supplier must be held responsible for the safe operation of the new equipment and its interface with existing equipment designed by others. A sole-source procurement typically involves the airport first developing a set of technical requirements and purchasing terms and conditions. These requirements are then transmitted to the supplier with a request for technical and price proposals. Through a series of technical and contractual negotiations, the airport's requirements and the supplier's proposal are merged into a mutually agreeable contract document.

The second procurement approach (overlay) is used to establish a competitive environment where two or more APM providers are invited to propose on the overhaul of the existing APM. The competitive procurement is intended to provide the airport with the most favorable market price for the

work. In this type of procurement, a complete set of technical requirements and purchasing terms and conditions are generated and published by the airport, with responses solicited from interested system suppliers. In order to allow a fair evaluation of the APM suppliers' bids, there is usually little or no pre-bid negotiation of the contract requirements.

For most APM overhauls, the airport typically would choose either competitive or sole-source for the entire system as compared to selecting competitive for PDS and sole-source for ATC. Also, even with a competitive procurement based on the overlay approach, there are some aspects of the installation, such as the platform door control, that would need to be phased in (possibly with some support of the original supplier under a smaller sole-source contract). The overhaul approach decision should be based more on the total scope of the proprietary systems overhaul than it is on which subsystems are to be overhauled.

12.2.3 Overhaul Technical and Schedule Considerations

Planning for an APM overhaul differs significantly from that of a new APM system. The following are some specialized areas that should be specifically addressed as part of the overhaul planning activity.

Back-up transportation plan—While most operational APMs have back-up transportation plans in the event of rare and unexpected outages, it is more likely that such an outage will occur during an APM overhaul. This is primarily due to the fact that the APM system operation is likely already degraded in order to support the installation activity. Also, many APMs include special operational modes for failure recovery. However, during the project some of these failure-recovery modes of operation may not be available as a consequence of construction activities. For these reasons, the airport must have a contingency plan to notify and guide passengers to the alternate mode(s) of transportation. This back-up transportation scheme should be carefully planned, staffed, and supplied with equipment so that it is capable of operating for an extended period of time.

Safety certification of interim configurations—The certification of system safety is typically addressed toward the end of a new APM installation project. However, during an APM overhaul, it is likely that there will be several interim configurations of the system. Therefore, it is important to plan for these interim system safety certifications.

Configuration control—During an APM overhaul, it is likely that the APM system will go through several configurations as old equipment is removed and new equipment installed and commissioned for passenger service. Since the maintenance of the APM must be ongoing throughout the project, it is essential that up-to-date documentation of the configuration at each interim phase is provided to the operations/maintenance staff. Briefings should be conducted for all O&M staff prior to any change in the system configuration to minimize the possibility of system down-time resulting from a failure.

O&M staff training—As mentioned with respect to the system configuration control, it is important that all O&M staff be trained in the various overhaul project phases. This training must be supported by interim maintenance manuals, which should be provided to the staff several months in advance of the training and equipment commissioning. Due to the additional time required to support both the ongoing maintenance and the training, additional O&M manpower (or overtime) should be scheduled during the project.

Space constraints—During an APM overhaul project there are basically two systems in operation: the existing system and the system as modified with new components. This creates a requirement to provide space for both old and new equipment. Frequently the new equipment is temporarily co-located with existing equipment. In such cases it is important to consider power and cooling capacity for the equipment rooms and spaces. The overlapping of system activities may also require that adequate spare vehicles be maintained for both existing operations and for new system testing.

System availability—System availability requirements for an APM are typically specified in the contract, with financial penalties if the target availability is not achieved. Since an APM overhaul introduces new components into passenger service well in advance of final work completion, an availability impact study should be undertaken in order to establish appropriate system availability levels for each phase or configuration for the project.

Warranty of overhauled components—In a system overhaul, various components and equipment will be placed into service at different times during the several phases or configurations of the project. For this reason, it is necessary to clearly establish when the warranty period for each component/equipment begins. While some airports accept the beginning of the warranty period as the date of passenger service for the component, other airports require that the warranty period commence only when the complete overhaul work achieves substantial completion. While this approach simplifies record keeping, it comes with additional costs because the APM

supplier will need to extend the equipment manufacturers' initial warranty periods at its own expense.

Although detailed planning of an APM overhaul project may be complex and involves numerous iterations of alternative considerations, use of the guidelines and recommendations described above should assist in identifying potential project risks and help ensure the success of the project while maintaining an acceptable level of ongoing passenger service. As the APM industry approaches its 40th year of successful operations at airports, there is now a track record of APM systems that have operated beyond their original useful life and have been successfully overhauled. Knowledge of these overhaul projects and the lessons learned will be invaluable to any airport that is planning for the overhaul of its APM system or components.

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APPENDIX A

Theoretical Examples of APM Planning and Implementation

Introduction

This appendix presents two theoretical examples of the planning process for an APM system at an airport. The examples demonstrate applications of the methodologies and planning criteria in the guidebook to produce plans for two APM systems. It also describes the applicable metrics and measurement tools to both qualitatively and quantitatively evaluate the alternatives and select an optimal solution.

The two examples in this appendix consist of a pinched-loop system and a shuttle system. These are two common types of APM system configurations, and their examples demonstrate the APM technology considerations from Chapters 6 and 7, as well as the planning criteria of Chapter 8. These previous chapters, particularly Chapter 8, should be consulted in conjunction with this appendix. The focus of this appendix is on the process of APM planning more than on the technical design details of an APM system presented in the chapters.

It should be noted that while the two theoretical examples have some clear differences (airside vs. landside, shuttle vs. pinched loop, etc.), there are some planning steps that are similar; therefore, there are some sections in this appendix where the text is repetitive between the two examples

Flowcharts

Throughout the description of the APM planning process, this appendix provides both summary and detailed flowcharts outlining the planning processes for two theoretical airport APMs; a self-propelled airside pinched-loop system and a cable-propelled landside shuttle APM system at a hub airport. The flowcharts highlight the similarities as well as the differences in the planning process between the two examples, and include a graphic key. Many findings have been made throughout the planning process for each example. These findings appear in the flowcharts as decisions (diamonds) and were arrived at through an analysis of existing APM systems with similar characteristics to these theoretical systems. Outputs of the "Operations & Maintenance Costs," "Capital Costs," and "Evaluate System Level of Service" process blocks are shown as data outputs (parallelograms) rather than decisions (diamonds). This was done to show that costs and level-of-service measures are fixed outputs based on the many decisions that are made during APM system planning. Once the system parameters are defined, cost becomes a fixed output (although in practice system parameters may be re-defined to meet cost limitations). Level of service also becomes fixed once system parameters are defined, but the flowchart shows a dashed line connecting level of service to all system-defining decisions. This was done in order to show how level-of-service considerations influence system parameters throughout the planning process and may be used to fine tune system parameters.

Although the flowcharts are intended to be self-explanatory, this appendix's text is offered as a supplement and amplification of the planning actions depicted in the process boxes (squares) contained in the flowcharts. These can be categorized into three main categories, with major issues within each category bulleted as follows:

1. Operational considerations:
    - System level of service
    - Alignment
    - Ridership
    - Capacity analysis
2. Technical considerations:
    - Power distribution
    - Maintenance and storage facility analysis
    - Command, control, and communications analysis
    - Station and passenger flow analysis
3. Cost considerations:
    - Operations and maintenance costs
    - Capital costs
    - Cost–benefit analysis
    - Financial strategies

A summary APM planning flowchart is provided below as Figure A-1 and depicts the general airport APM planning process applicable to both the airside and landside examples. More detailed zoom-ins of the general flowchart are provided at appropriate places within this appendix to illuminate specific issues in the airside and landside planning processes.

Assumptions

The flowcharts depict the planning process specifically for an APM system and assume that the airport has already come to the conclusion that they wish to plan an APM system. The charts do not include any reference to other technologies that might be considered as alternatives to an APM such as shuttle buses. It is assumed that any such alternatives have already been eliminated through an earlier multimodal alternatives analysis or are not of interest to the airport.

All flowcharts assume that the APM system is being planned for implementation at an existing airport as opposed to being part of an airport's initial construction. This assumption is made to reflect the most common scenario likely to face those planning the APM. Although the most recent APM planned as part of the initial construction of a major airport in the United States was at Denver International Airport, which opened in February of 1995 and is not likely to be repeated, other airports outside of the United States are implementing APM systems as an integrated part of initial construction. An example, occurring as this guidebook is being produced, is the New Doha International Airport in Qatar. For these rarer examples of new greenfield construction, the planners should proceed with the self-evident assumption that certain processes described in the flowcharts will be considerably less constrained, particularly those dealing with physical and spatial issues such as the guideway alignment and the location of the maintenance and storage facility.

Closer examination of the similarities and differences between the two flowcharts reveals more similarities than differences. This is indicative of the conceptual commonality in the planning process for APMs of different configurations. Because of this fact, it can be assumed that the planning process documented in this appendix for Examples 1 and 2, the airside pinched-loop APM and the landside shuttle APM, respectively, can serve as a basic blueprint for the planning of many airport APMs of different configurations. There will be some differences among different APMs and the planning processes for the two examples reveal some of these differences. These differences can serve to typify the number, degree, and types of differences that would likely be encountered when planning for different APM systems at an airport.

Example 1: Planning an Airside Pinched-Loop APM System

For this discussion, refer to the Figure A-1 flowchart for a summary level process as well as the detailed flowcharts (Figures A-2 through A-6) referenced within certain sections. This discussion follows the more-detailed flowcharts; italicized notes provide cues for the reader to refer to specific aspects of the detailed flowcharts.

For Example 1, the first detailed flowchart (Figure A-2) commences with stating the principal need: "Airport wants to investigate an APM to provide service between terminals to benefit transfer passengers." For airside APM systems, it is the transfer passenger that typically drives the need for an APM system. Specifically, for large hub airports, it is common for an airport to grow or develop a master plan for growth when:

1. The distances between connecting gates become too great to be traversed by unassisted walking or moving walkways within the allotted online or interline connection times; and/or
2. The location of connecting gates becomes segregated or separated by airfield elements (runway) or other elements whereby surface transportation, such as buses, cannot operate.

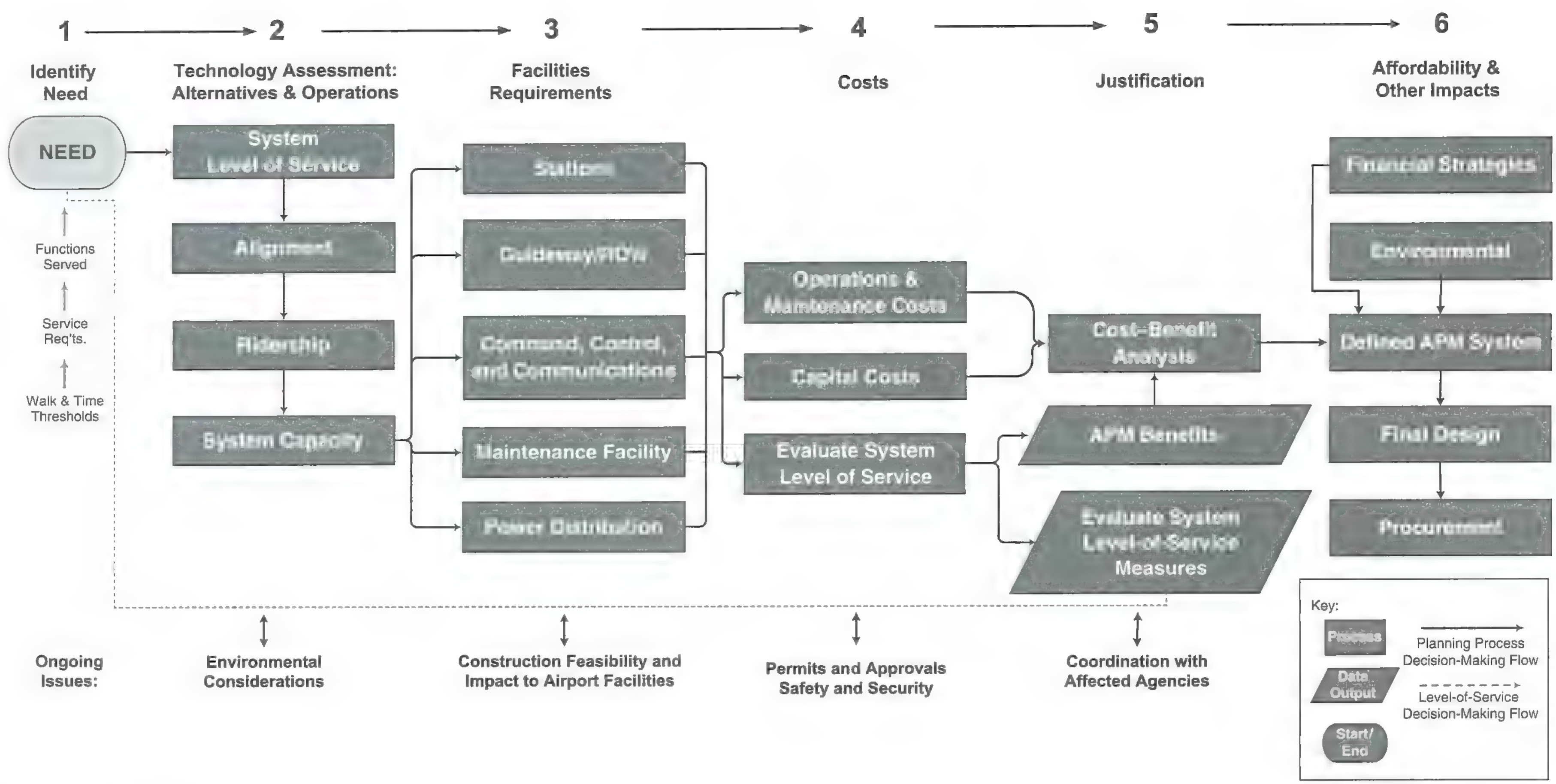
Although the assumptions for this appendix state that an APM has already been selected over alternate systems such as a busing system, the point of this discussion is to stress that airside APM systems can often be easily justified. For example, the two preceding conditions (1) and (2) leave virtually no choice but to plan for an APM. In smaller, non-hub airports, an airside APM may also be justified by the convenience and/or level of service provided to the passengers.

Operational Considerations

A prerequisite for the successful planning of an airside APM is to plan the system around project-specific operational considerations and not to plan the system around a specific APM technology and its characteristics. The following discussion amplifies the operational considerations listed in the process blocks of the flowchart.

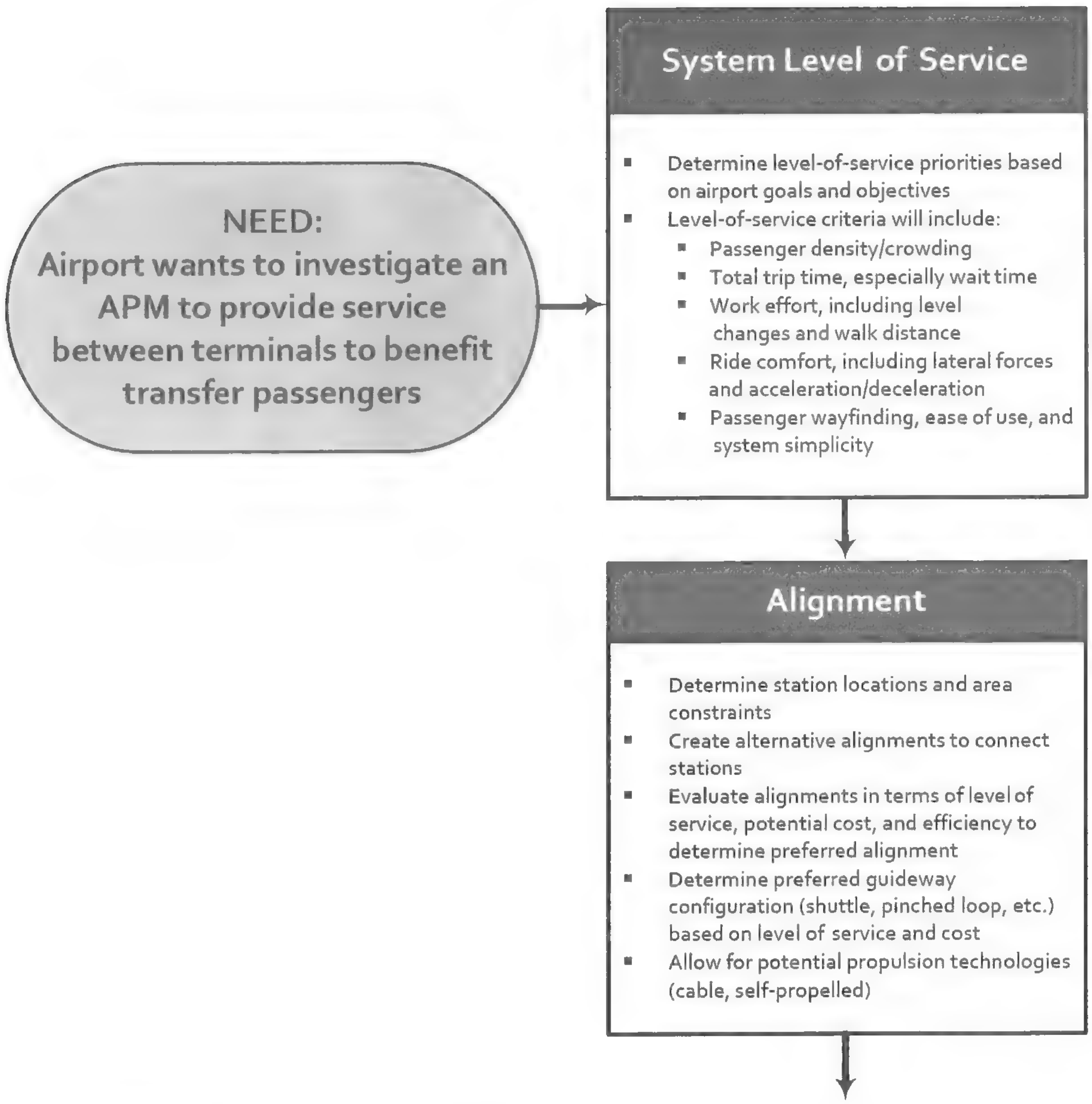
System Level of Service

- **Determine the level of service priorities based on the airport's goals and objectives.** One may initially assume that all APM systems should strive to be designed to offer the highest level of service possible. However, this is not necessarily the case. An example is to compare a must-ride system such as Denver International Airport's (DIA) APM with the concourse tram APM at Minneapolis International



Source: Lea+Elliott, Inc.

Figure A-1. Summary airside APM planning process.



Source: Lea+Elliott, Inc.

Figure A-2. APM operations planning process.

Airport (MSP). The DIA system was planned with a level of service in terms of redundancy, headway intervals, and availability that were all more critical than for the MSP system because it provides the sole means for passengers to reach their gates. The MSP system provides an appropriately high level of service, but was planned with the consideration that passengers have the option of walking or taking moving walkways to their gates if desired. Thus, certain level-of-service factors (such as redundancy) were not as important.

Other level-of-service planning criteria include:

- **Passenger density and crowding.** Passengers choose to stop boarding a train when they perceive that the train is full. Thus, although it is not possible to assume passengers will crowd onto a train, certain planning parameters can result in different levels of density on the station platform. As such, the acceptable level of density should be determined from a planning standpoint. The options span from planning for minimum waiting times with virtually no passenger queue to (in rare cases) actually assuming missed trains are acceptable during peak hours.
- **Passenger effort, including level changes and walk distance.** A generally accepted planning assumption is that fewer level changes are desirable because level changes not only increase passenger effort (even with escalators) but also inhibit passenger wayfinding. A general planning assumption is that less walk distance is desirable. In some loca-

tions, walk distance is defined as the distance the passenger actually walks, not the distance the passenger travels (while standing on moving walkways for example), while in other locations, planners sometimes assume that passengers walk on moving walkways.

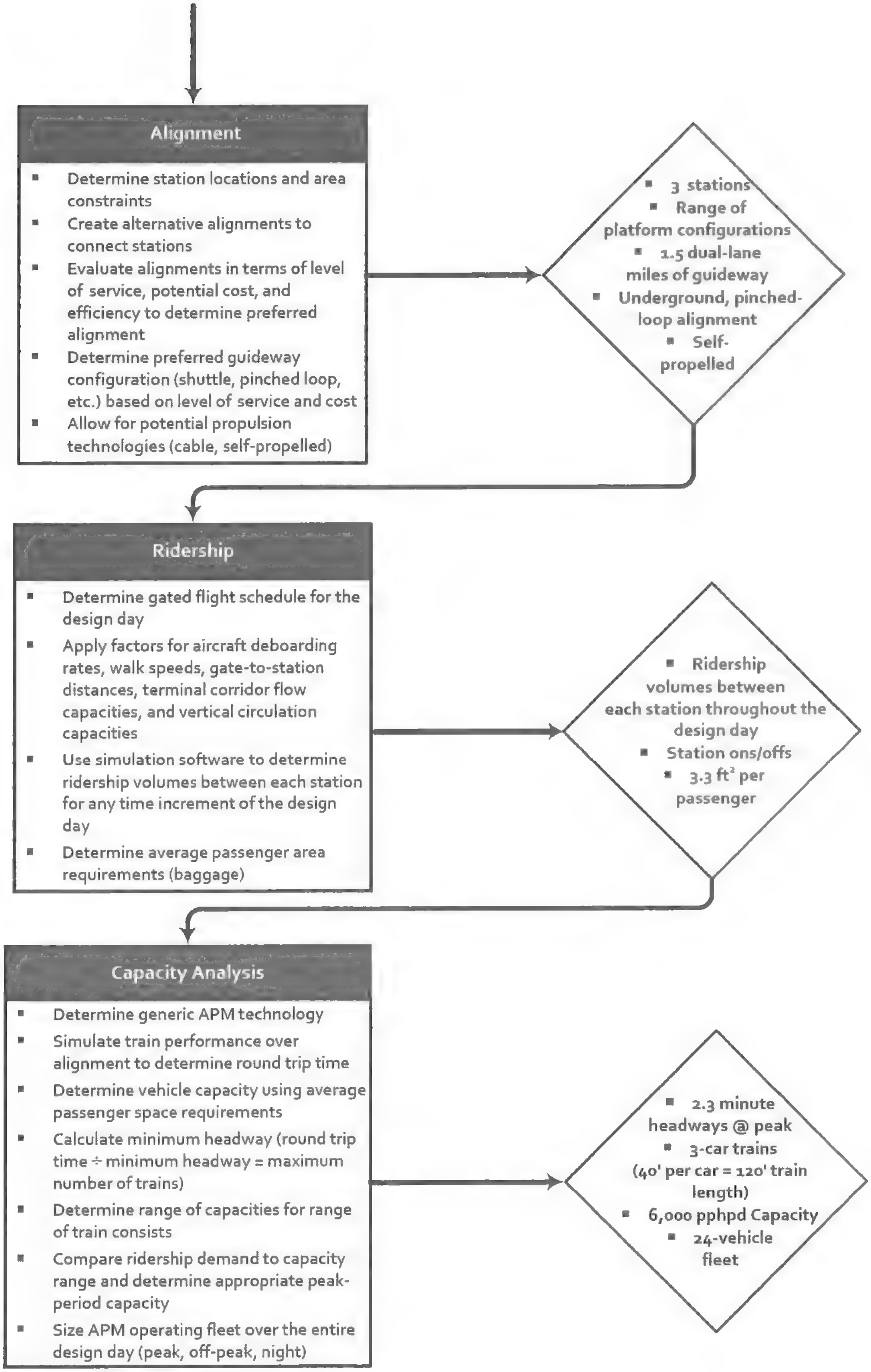
- **Ride comfort, including lateral forces and acceleration/deceleration.** Such forces are typically specified in terms of allowable maximums set by pre-established industry standards. These standards exist not only for comfort, but for safety. However, in certain cases, exceptions may be made. For example, when particular guideway alignment options dictate a vertical grade beyond normal practices, certain ride comfort factors will be degraded.
- **Passenger wayfinding, ease of use, and system simplicity.** A generally accepted planning assumption is that simplicity of wayfinding is desirable. Specifically, minimizing the number of decision points that the passenger must make is desirable. All APM systems require audio and visual (signage) cues because they typically require self-use by the passenger, without attendants. One widely accepted way to effectively use directional signage is to avoid referring to the APM system except when absolutely necessary. For example, passengers are simply signed to their appropriate gate, and the train ride to that gate becomes incidental.

Alignment

- **Determine station locations and area constraints.** Planning for the number, spacing, and placement of the stations should provide the maximum convenient service to the largest range of users with the fewest possible number of stations. Planning for the fewest practical number of stations needed to provide the appropriate level of service helps the economy and efficiency of the system in terms of fleet size and reduces the capital and O&M costs of both the APM system and the associated fixed facilities. Planning for future potential expansion must also be incorporated.
- **Create alternative alignments to connect stations.** The actual guideway alignment is a means to an end. The end is to serve the stations that have been located to meet various project-specific parameters. The most efficient guideway alignment is typically one that is perfectly straight and perfectly level, but in real-world planning it is seldom possible to provide such a guideway, particularly when introducing an APM into an existing airport environment. However, there is typically an optimal geometrical guideway alignment to connect the planned stations, and the most effective way to determine such an alignment is to evaluate a range of different alignments.
- **Evaluate alignments in terms of level of service, potential cost, and efficiency to determine preferred alignment.** Using the different alternate alignments that have been developed, consider how the level of service, cost, and system efficiency are affected by the specific differences in the alternatives. These differences may include aerial versus subgrade and/or combinations of aerial and subgrade alignments. Additional areas for evaluation include the alignment's impact on existing facilities, impact on future growth potential, ease of expandability, and ease and/or possibility of phased implementation. Specifics regarding the alignment configuration should also be evaluated, particularly for associated cost implications. For example, in a dual-lane system, bringing the two guideways close together where possible along the alignment allows shared use of a single, central emergency walkway as opposed to having two separate emergency walkways. Also, the supporting structure will typically be more economical due to reduced forces in the columns, bents, and foundations when the distance between two parallel guideways can be minimized.
- **Determine preferred guideway configuration (shuttle, pinched loop, etc.) base on level of service and cost.** Somewhat simultaneously with the exploration of various guideway alignments, various configurations of the guideway should also be developed at a conceptual level. For instance, a two-way loop configuration may provide the needed level of service, but further exploration may reveal that a pinched-loop configuration provides an equal level of service yet gains an economic advantage by not needing the construction of as much guideway in terms of single-lane feet. For an airside hubbing application, the number of airline gates to be connected often dictates three or more APM stations, and the required gate-to-gate connect times dictate very low headways. This combination of longer distance and shorter headways typically results in selection of a pinched-loop guideway configuration.
- **Allow for potential propulsion technologies (cable-propelled, self-propelled).** Some aspects of a guideway's alignment have differing effects on different propulsion technologies. For instance, LIM propulsion is typically more sensitive to grades. Also, certain cable technologies are more sensitive to vertical curves (particularly concave or "sagging" vertical curves) because the cable may lift from the sheaves in certain instances. More detailed design analysis is required to confirm and/or solve such specifics, but the planner should be aware of such issues even in the early planning stages of the APM.

As noted in the guideway configuration paragraph above, an airside hubbing application typically requires an alignment length and system frequency that dictates more than two trains operating, and therefore a self-propelled technology operating on a pinched-loop configuration.

The reader is encouraged to note the decision diamond in the Figure A-3 flowchart where the theoretical airside system has



Source: Lea+Elliott, Inc.

Figure A-3. APM capacity planning process.

now been planned as a self-propelled, pinched-loop system with 3 stations and 1.5 miles of underground dual-lane guideway. The decisions reached for this theoretical example (self-propelled, pinched-loop, underground, etc.) are common decisions found in actual airside APMs at large hub airports with many transferring passengers. Specific decisions at each airport depended on the site-specific environment. Reasons for the decisions in our theoretical example may be as follows:

- *Self-propelled and pinched loop—At a large hub airport there are multiple terminals being connected via the APM, and the relatively long alignment (and high service frequency requirement) dictates multiple trains in operation and therefore a pinched-loop alignment and self-propelled technology.*
- *Underground—At a large airport with multiple terminals separated by an active aircraft apron, an underground alignment is typically the only solution.*

Ridership

- **Determine gated flight schedule for the design day.** The airlines' current or projected flight schedules are key instruments in answering the basic ridership questions of how many people need to go where and when. However, answering these basic questions is seldom simple because airlines may not have flight schedules projected into the appropriate future years, and if they do, their accuracy is always uncertain due to inevitable change. Thus, it is accepted that the planner must take a conservative approach in ridership calculations, erring on the side of higher ridership when presented with unknowns. This is borne out by the fact that all APM systems at major airports have consistently incurred increased ridership over time, whereas this has not universally been the case with APMs in urban settings.
- **Apply factors for aircraft boarding rates, walk speeds, gate-to-station distances, terminal corridor flow capacities, and vertical circulation capacities.** Such factors are fairly standardized and accepted among aviation and transportation planners. These standard factors should be used unless special circumstances dictate otherwise.
- **Use simulation software to determine ridership volumes between each station for any time increment of the design day.** This is a specialized task that is most appropriately assigned to an entity with the tools and experience to calculate the ridership volumes between each station, the deboardings and boardings at each station, and the system's peak link. In addition to the design hour of the design day, ridership is typically analyzed and determined for a variety of off-peak hours in order to accurately estimate how the APM system will operate throughout a typical 24-hour period.
- **Determine average passenger area requirements (baggage).** This varies by project, particularly between airside and landside systems. Passenger area requirements are expressed in area (square feet or square meters) for each standing and seated passenger, respectively. In the case of the theoretical airside system, it is assumed passengers will have smaller, wheeled carry-on bags onboard the trains, and the space per passenger should be calculated accordingly. Changes to airport security requirements (carry-on baggage) and to baggage design (size, roller capability, etc.) require planners to continually update these passenger area requirements.

The reader is encouraged to note the decision diamond in the flowchart in Figure A-3 where the theoretical airside system has now been planned to provide for 3.3 square feet per passenger based on known ridership volumes between each station throughout the design day and the number of station deboardings and boardings.

Capacity Analysis

- **Determine generic APM technology.** The actual technology of an actual APM supplier is not assumed for this step. Rather, the planner should determine/develop a generic APM technology that is generally representative of several actual APM suppliers. This will help ensure healthy competition among multiple suppliers that may ultimately provide a system in accordance with the performance specifications to be developed during the design phase and after the planning phase of the system is completed. An example involving generic APM technology would be the assumption of using a generic 40-foot vehicle because many APM suppliers produce a vehicle close to a 40-foot length. Good knowledge of the major APM supplier's technology is crucial for the exercise since some are configured in married pairs while other suppliers only offer vehicles less than 40-feet long.
- **Simulate train performance over alignment to determine round trip time (RTT).** This typically requires the use of specialized computer modeling in all but the most simply configured APM systems. As performance does vary among technologies, it is best to assign train performance simulation to an entity with experience in this specialized field.
- **Determine vehicle capacity using average passenger space requirements.** In this planning task, the generic 40-foot vehicles can be assumed to accommodate a certain number of standing and seated passengers based on the planned 3 to 4 square feet per passenger—say 3.3 square feet per passenger.
- **Calculate the train headway (round trip time ÷ headway = number of trains).** This calculation is self explanatory. Although the RTT and headway (HW) can be accurately modeled and estimated, a certain amount of professional judgment and expertise should be applied. For example, in calculating the RTT, inputs to the simulation model should

consider that the particular dwell times at different stations may differ, and their durations should be estimated. For instance, a lightly loaded station may function well with dwell times as low as 20 to 30 seconds, whereas a heavily loaded station may typically require dwell times exceeding 1 minute. Switch location is an important factor in the round trip and HW calculations.

- **Determine range of capacities for range of train consists.** For this planning task, a variety of APM performance criteria must be considered together in order to ensure that the most efficient system is developed. For example, it may have been determined that the minimum calculated HW is not necessary to achieve the desired level of service. Yet it may also be determined that by using the absolute minimum HW, four trains would be able to operate instead of three trains. Assuming the generic 40-foot vehicles, it may also be determined that the required capacity could be attained by running four two-car trains instead of three-car trains. Note the positive domino effect resulting from the difference in these train consists: the total operational fleet can be reduced from nine to eight vehicles, all station platforms can be reduced in length by 40 feet, and the number of platform automatic door sets can be reduced by two or three sets per platform depending upon the actual supplier—all with no reduction in capacity but actually with an increase in level of service due to the shorter headways.
- **Compare ridership demand to capacity range and determine appropriate peak-period capacity.** This task determines the peak link during the peak period of demand. The peak link is defined as the link between successive stations that has the highest ridership demand. Although other links between stations will have less ridership demand, it is the single peak link that drives system capacity.
- **Size APM operating fleet over the entire design day (peak, off-peak, night).** Because ridership demand varies over the day, the capacity of the APM system should be adjusted to match demand to the greatest degree that is possible. Having more trains in operation than is necessary during an off-peak period incurs unnecessary wear and tear on the trains and related equipment, shortens major and minor maintenance intervals thus increasing maintenance costs, and incurs unnecessary power consumption. Therefore, the operating fleet should be planned to accommodate different ridership demand scenarios over the design day, and if possible, also accommodate seasonal ridership differences and holiday peak periods that may last from a few days to a few weeks. There are also energy-saving opportunities during off-peak and night operations that can be achieved with a detailed power consumption (load flow) analysis.

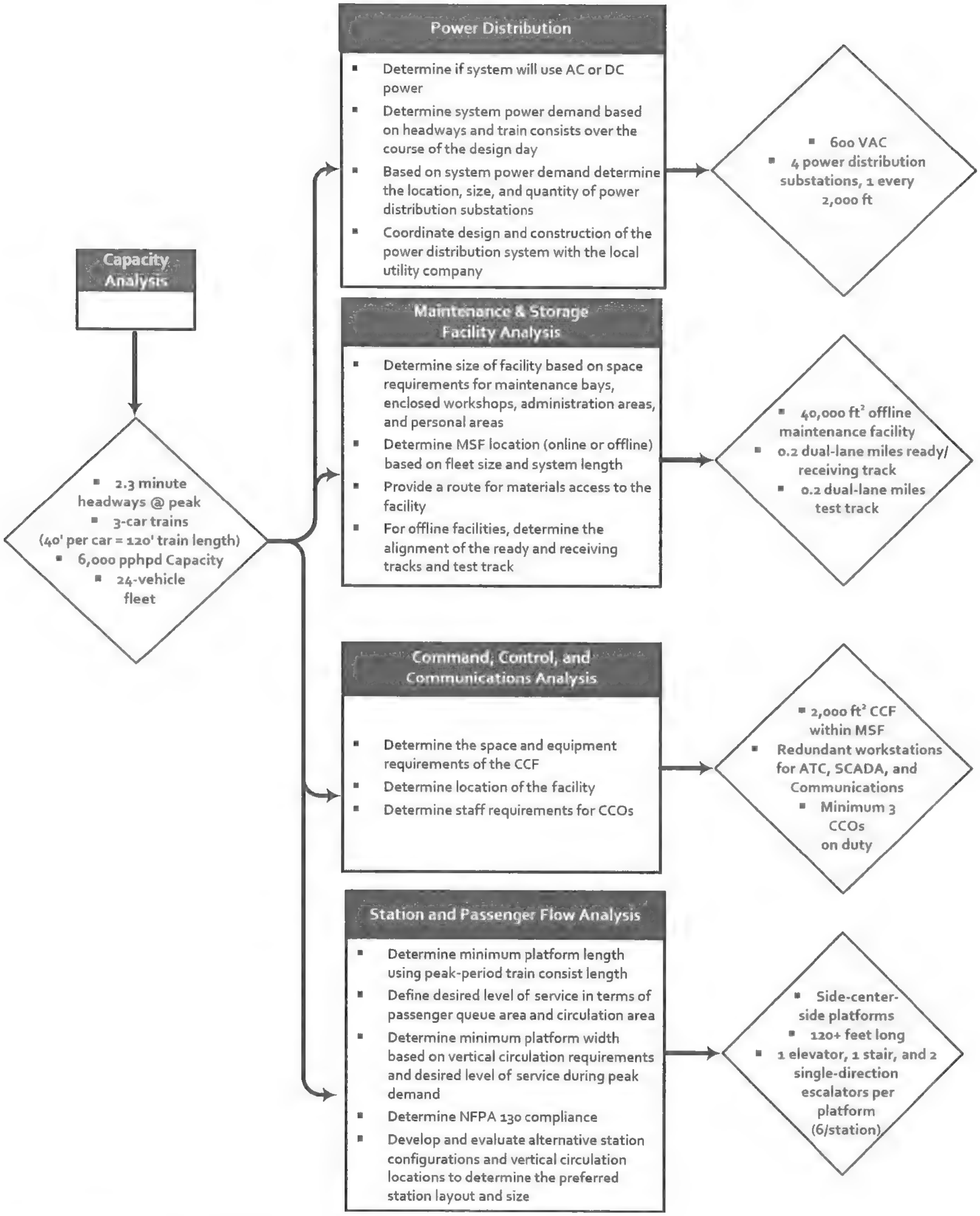
The reader is encouraged to note the decision diamond in the Figure A-4 flowchart where the theoretical airside system has now been planned for a 6000 pphpd capacity to be met with a 24-vehicle fleet with three-car trains (40 feet per car = 120-foot train length) operating during peaks at 2 to 3 minute headways.

Technical Considerations

The successful planning of an APM also involves consideration of technical aspects of the system. Each APM system is proprietary and is therefore unique with regard to many particular technical aspects. The challenge to the APM planner is to appropriately plan the system in accordance with known technical considerations yet not to a degree so specific that certain suppliers are unable to provide a viable system. This increases competition, which is in the best interests of the airport. The following discussion amplifies the technical considerations listed in the process blocks of Figure A-4.

Power Distribution

- **AC or DC propulsion power distribution?** Although the actual onboard traction motors that propel APM vehicles are universally AC, the propulsion power distribution system that provides power to the vehicles along the guideway may be AC or DC, depending on the particular supplier. Although there are advantages and disadvantages to each, from a planning perspective it is not useful to assume one is better than the other or to attempt to predict which will be used. Rather, it is important for the planner to understand the differences between the distribution systems that affect the high-level planning of the system. For instance, power distribution substations for a DC system can be located further apart than those of an AC system. More and larger equipment within the substation is required for DC systems. Thus, substation space requirements will be greater for DC systems. DC ground current is of greater concern than that of AC, and may require corrosion control measures and current testing facilities that are not required for AC systems.
- **Determine system power demand based on headways and train consists over the course of the design day.** The system's power demand will be used in O&M budgetary planning by the airport and will also be needed by the local utility company that will provide the high-side power to the APM. The power demand may be manually derived for small systems, but computer modeling of power demand is virtually essential for larger systems with multiple trains and changing train consists.
- **Based on system power demand, determine the location, size, and number of power distribution substations.** This is where some of the differences in planning for an AC or DC system will come into play. However, regardless of AC or DC power distribution, some planning rules of thumb



Source: Lea+Elliott, Inc.

Figure A-4. APM technical planning process.

are applicable. Generally, the substations should be located directly adjacent to the guideway if possible. If multiple substations are required, their general locations should be located equidistantly along the guideway, and equidistant from each other to the degree possible, in order to minimize voltage drops and increase efficiency. Each substation will require access for equipment and personnel, including on-site parking and loading areas. Housekeeping power to the substations must also be planned for. Energy storage (i.e., captured through regenerative braking) equipment should also be considered.

- **Coordinate design and construction of the power distribution system with the local utility company.** This task involves coordinating the layout of the physical aspects of the power distribution system. For instance, the local utility company may provide and install the power service entrance or what is sometimes referred to as the distribution yard. In addition, certain electrical design aspects of the distribution system must be coordinated with the local utility company. For example, regenerative braking enhances energy efficiency by capturing braking energy and feeding it back to other trains or back to the utility. However, some utility companies will not allow this. AC systems are more likely to induce harmonic noise on the utility distribution lines. This may require harmonic filtering, and this should also be coordinated with the utility company.

The reader is encouraged to note the decision diamond in Figure A-4 where the theoretical airside system has now been planned as a 600 volt AC system with four power distribution substations located approximately every 2,000 feet.

Maintenance and Storage Facility Analysis

- **Determine size of facility based on space requirements for maintenance bays, enclosed workshops, administration areas, and personnel areas.** For larger systems configured in a loop or pinched loop, the MSF is offline and typically includes an adjacent storage and switching yard. (Shuttles tend to have online MSF at a terminus station.) Maintenance bays for an offline MSF include heavy and light bays where long term and short term maintenance tasks are performed, respectively. Although the MSF is a specialized building type, architectural and engineering firms require no specialized expertise to design and produce the construction documents for the MSF once it is programmed. However, it is this architectural programming that is critical to the success of the MSF. Planning for the MSF should also consider any possible expansion of the system.
- **Determine MSF location (online or offline) based on fleet size and system length.** An offline maintenance facility is typical for multi-station, pinched-loop systems and should be located adjacent to a mainline guideway so that a minimum amount of non-revenue guideway is required for access. APM maintenance facilities are unlike a bus maintenance facility in that they are clean and quiet (because internal combustion engines are not involved). Thus, from a planning perspective, the MSF may be located in sensitive areas, such as within an airport terminal building, without negative impacts.
- **Provide a route for delivery of materials to the facility.** This includes site access that can accommodate trucked deliveries, including full-size tractor-trailers on occasion. A route for material delivery applies not only to the siting of the MSF but to circulation within the facility itself. Planning should dimensionally accommodate a forklift with pallets in and around all maintenance bays, including a path to parts storage or other accessed areas. Planning should accommodate delivery and storage of items that will not fit within a freight elevator. One example is replacement power and signal rail, which typically comes in 40-foot lengths.
- **For offline facilities, determine the alignment of the ready and receiving tracks and the test track.** The ready (or departure) track and the receiving track are sections of guideway located between the mainline guideway and the offline MSF yard. These tracks function as hand-off or transition areas for trains leaving and entering the maintenance yard to and from revenue service. The ready track is the staging position for a fully serviced and powered train that is ready to be inserted into revenue service at the desired time. The receiving track is the section of guideway where a train is handed from revenue service into maintenance. This transition is both physical and electronic, involving both the automatic train control system and maintenance staff. From a planning perspective, the significant requirement is that both of these guideway areas must accommodate a train of maximum length and ideally, although not absolutely, should consist of tangent sections of guideway.

  The test track is a non-passenger-carrying section of guideway where dynamic testing of trains can be performed before putting them into passenger-carrying service. Ideally, the test track should be tangent and of a length that allows a maximum length train to reach maximum speed. For a four-car train of generic 40-foot vehicles, this length is approximately 1000 feet. From a planning perspective, if space is at a premium, a shorter test track is superior to no test track.

The reader is encouraged to note the decision diamond in Figure A-4 where the theoretical airside system has now been planned to include a 40,000 square foot offline maintenance facility, 0.2 dual-lane miles of ready/receiving track, and 0.2 dual-lane miles of test track.

Command, Control, and Communications Analysis

- **Determine the space and equipment requirements of the central control facility.** The size and layout of the CCF varies somewhat in proportion to the size of the APM system. However, all CCFs have basic requirements that must be planned for. These include a control console with system mimic screens, and CCTV monitors for station (and possibly other) surveillance, all within sight of the central control operators. Typically, an APM equipment room is located directly adjacent to the CCF. The specific requirements for the equipment and layout of the facility must be considered to ensure that an adequate spatial footprint is reserved in the planning stage. The CCF should be planned to accommodate additional equipment and/or personnel required for future expansion of the system if such expansion is anticipated.
- **Determine the location of the facility.** From a planning perspective, combining the CCF with the MSF (locating the CCF within the MSF) is typically a solution that allows functional consolidation and efficiencies. If the CCF is located remotely from the MSF, some duplication of minimum essential facilities such as restrooms and administrative space may be required. The initial location planned for the CCF should be considered its permanent location, and any possible expansion or changes to adjacent or surrounding facilities that could cause disruption to the CCF should be considered when choosing this location. Although CCFs have been successfully relocated, the CCF is the electronic center of the APM system; thus, such relocations are difficult, expensive, and invariably cause significant operational disruptions.
- **Determine staff requirements for Central Control Operators.** Adequate staffing and the number of CCOs should be considered with project-specific requirements. As a general rule, a minimum of two CCOs should staff the CCF at any time. The total number of CCOs on staff will depend upon system size, shift arrangements, and benefit (particularly leave) factors.

The reader is encouraged to note the decision diamond in Figure A-4 where the theoretical airside system has now been planned to include a 2,000-square-foot CCF located within the MSF with redundant workstations for ATC, SCADA, and communications with a minimum of three CCOs on duty.

Station and Passenger Flow Analysis

A prerequisite note regarding the following bullets is that architectural programming and analysis is critical to the successful planning of the stations. Also, reference Section 8.4, Stations, for additional detailed discussion regarding the programming of APM stations.

- **Determine minimum platform length using maximum period train consist length.** Various queuing areas for passengers must be taken into account when the total platform length is determined. These include queues for the trains, as well as for escalators and elevators. If future expansion plans call for increasing the number of vehicles per train, then the platform must be sized to accommodate this future train length. In these cases, the automatic station doors for the future vehicles are typically not installed, although their positions are reserved by removable window wall assemblies or some type of removable panels. In some instances, the future automatic station door sets may be procured and installed prior to their actual activation.
- **Define desired level of service in terms of passenger queue area and circulation area.** This level of service can range from planning for virtually no waiting queue to, in rare occasions, missed trains being an acceptable situation during peak periods. For an airside APM serving hubbing airline passengers, the prospect of missing an APM train due to crowding would not be acceptable due to the time sensitivity of gate-to-gate travel. In all cases, passenger queue area depends upon the headways of the trains to a large degree, and thus should be planned in conjunction with the trains' performance parameters. The circulation on an APM platform typically implies circulation paths to and from the trains and to and from vertical circulation elements only. This is because no other functions typically exist on the platform. For instance, it is not recommended to install seating, vending machines, newspaper racks, telephone banks, flight information display systems (FIDS), or other such amenities on an APM platform. The short wait times on the platform do not permit use of such amenities without interfering with the primary purpose of the platform, which is to quickly and efficiently move people on and off the trains.
- **Determine minimum platform width based on vertical circulation requirements and desired level of service during peak demand.** This is a particular topic for which the reader is encouraged to review Section 8.4, Stations, for additional discussion. For larger APM systems serving an airline hubbing operation, it is likely that the queuing requirements for large numbers of passengers waiting for the trains will become the determining factor in establishing the minimum platform width. Also, the type of station is a key factor in determining minimum platform width. For example, a center platform station has a single area that must accommodate two functional platforms for trains arriving on either side. This single platform accommodates both boarding and deboarding passengers, and the fact that two trains may arrive at the same time must be considered. Side platform stations have platforms that accommodate only one train each, but each platform must have a full complement of vertical circulation elements and must

accommodate both boarding and deboarding passengers. A triple platform station (also referred to as a "side-center-side" or "flow-though" station platform) has three separate platforms, each with a full complement of vertical circulation elements. In this case, the center platform serves as a boarding platform only and the two side platforms serve only as deboarding platforms. The automatic door sets for the deboarding platforms open several seconds before the door sets for the boarding platform. This establishes the proper queue movement and allows the fastest and most efficient boarding and deboarding of the train, although this station type is the most expensive and requires the most overall space.

- **Determine NFPA 130 compliance.** An excellent guide for life safety issues is the National Fire Protection Association's "NFPA 130—Standard for Fixed Guideway Transit and Passenger Rail Stations." Its content is well researched and is dedicated to specialized life safety issues. For example, the NFPA 130 test for emergency egress from a station is not a typical/historical building code occupancy type analysis but rather an analysis of time, distance, and pedestrian movement that accurately reflects the real-world situation on the station platform. The reader is encouraged to review Section 8.4, Stations, for additional discussion on this topic. Egress from an underground airside APM system is of critical importance because passengers cannot be brought up to an active airfield apron.
- **Develop and evaluate alternative station configurations and vertical circulation locations to determine the preferred station layout and size.** The guidelines given in this appendix and in Section 8.4, Stations, provide only an overview of basic APM station design parameters. An architect, in collaboration with an APM specialist, should fully explore different station configurations within the context of project-specific and site-specific factors in order to develop the most appropriate specific station design(s).

The reader is encouraged to note the decision diamond in Figure A-4 where the theoretical airside system has now been planned to use side-center-side platforms approximately 120' long, with each platform having one elevator, one open stair (in addition to any required fire exits/stairs), and two single-direction escalators.

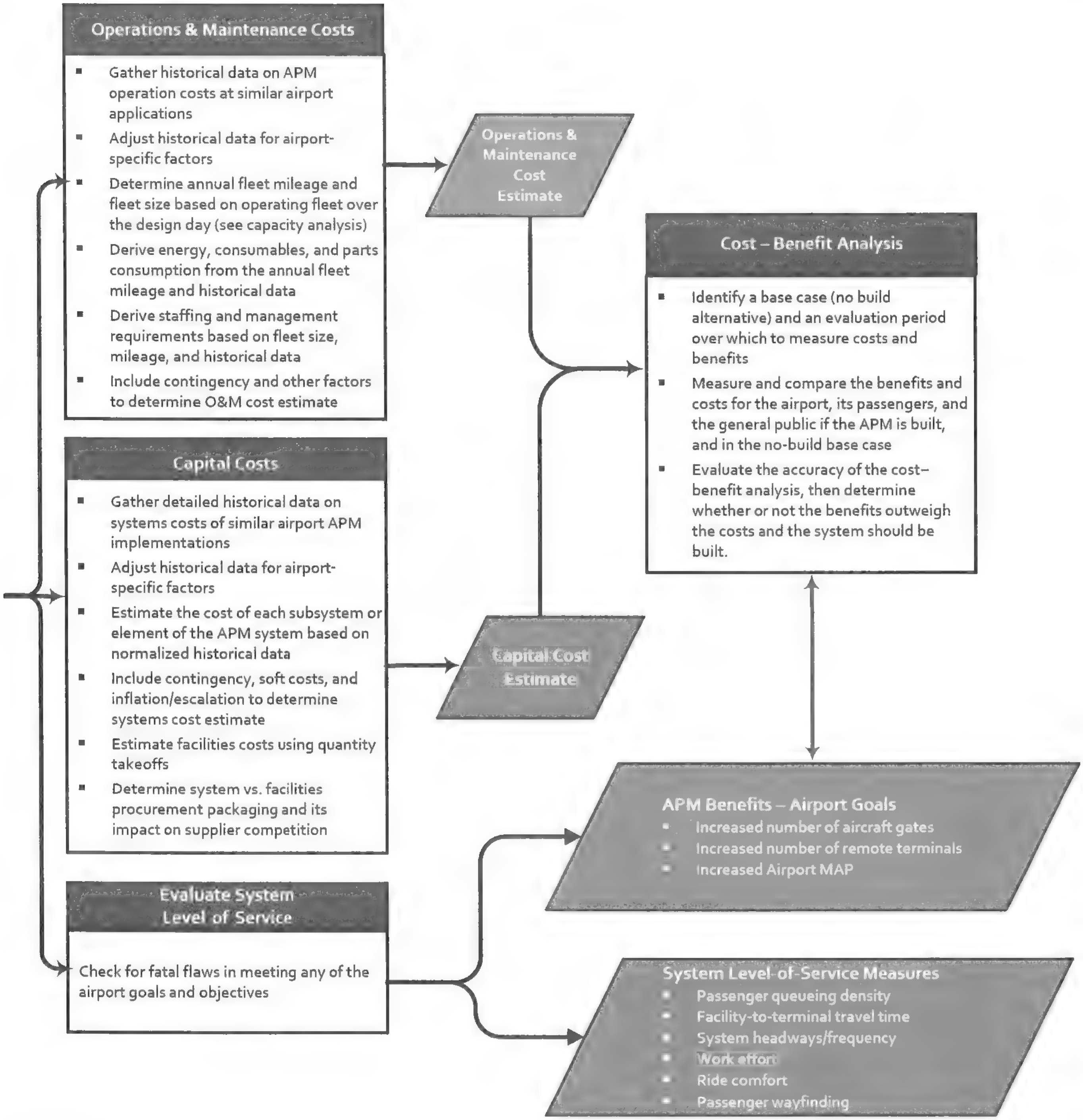
Cost Considerations

A variety of costs must be considered in the successful planning of an APM system. These costs include the initial capital costs required to implement the APM as well as the ongoing operations and maintenance costs of the system. In terms of APM planning, a cost–benefit analysis is recommended as a litmus test of the overall viability of the APM system. This section focuses primarily on APM system costs and not the costs of the system's associated fixed facilities. This is because the costs associated with the APM system's fixed facilities can be estimated by a professional estimating firm with no particular differences from other similar building types. The APM system costs, on the other hand, vary widely within the APM industry because each different APM supplier uses a different and proprietary technology. Costs for different projects by the same supplier may also vary significantly because of different scales of economy involving fleet size, capacity requirements, level of bid competition, and so forth. Thus, estimating and comparing the cost of a proposed APM system against standard industry costs is difficult because repeatable and consistent costs within the industry are quite elusive.

The following discussion amplifies the cost considerations listed in the process blocks in Figure A-5 and offers relevant points to be considered in preparing system cost estimates.

Operations and Maintenance Costs

- **Gather historical data on APM operations costs at similar airport applications.** A key consideration is to ensure, to the greatest degree possible, the similar nature of the APM systems for which the data is being gathered in terms of all operational and technical parameters. Since no two APM systems are identical, it is best to select a set of systems as similar to each other as possible and then adjust the O&M costs according to the known differences from the system being estimated.
- **Adjust historical data for airport-specific factors.** These factors can include the likelihood of union or open-shop labor and the associated local labor rates by category. Another airport-specific factor is the party that is intended to perform the O&M services, both initially and in the future. Options could include the initial supplier, a possible third-party provider by way of competitive bids, or the airport's own in-house staff.
- **Determine annual fleet mileage and fleet size based on operating fleet over the design day (see the Capacity Analysis section).** Factors considered in the capacity analysis must also be considered in determining the fleet mileage, which determines the wear and tear on the vehicle fleet, which in turn determines the frequencies of major and minor maintenance intervals.
- **Derive energy, consumables, and parts consumption from the annual fleet mileage and historical data.** Some additional options for the airport to consider are how and where particular O&M costs will be accommodated and budgeted for. For example, parts and consumables may be included in the annual budget for an airport's maintenance department, whereas the electrical costs for system operations may be included in the annual budget of an airport's utility department.



Source: Lea+Elliott, Inc.

Figure A-5. APM cost–benefit planning process.

- **Derive staffing and management requirements based on fleet size, mileage, and historical data.** Staffing for the APM system will consist of several different categories, and staffing will vary in proportion to system size and complexity. There are typically three work shifts that provide 24-hour coverage of the system 365 days per year. "First shift" typically refers to the shift most closely approximating 8 a.m. to 5 p.m. "Third shift" typically refers to the overnight shift, when the system is operating off-peak and wayside and other maintenance tasks are best accomplished. "Second shift" typically encompasses the 8 hours between first and third shifts. Staff categories typically consist of administrative and management, operations, and maintenance. The administrative staff typically includes a site manager and secretary or

other clerical positions. Administrative staff typically works first shift. Operations staff typically includes the central control operators as well as mechanics and mechanics' helpers. Operations staff must cover all three shifts. Maintenance staff typically includes electrical technicians, mechanical technicians, and their helpers. Although there is typically shift overlap between operations and maintenance staff members, most of the work of the maintenance staff is usually done during the third shift.

- **Include contingency and other factors to determine the O&M cost estimate.** The total O&M cost estimate will include factors such as contingency, escalation, overhead, and profit, and these factors are best determined and applied on a local and project-specific basis. Whether such factors are applied "above the line" or "below the line" in terms of labor and material subtotals is also best determined by the typical practices of the specific location and project.

Capital Costs

- **Gather detailed historical data on systems costs of similar airport APM implementations.** A key consideration is to ensure, to the greatest degree possible, the similar nature of the APM systems for which the capital cost data is being gathered. Since no two APM systems are identical, it is best to select a set of systems as similar to each other as possible and then adjust the capital costs according to the known differences from the system being compared.
- **Adjust historical data for airport-specific factors.** These factors can include the likelihood of union or open-shop labor and the associated local labor rates, by category, for appropriate building or highway labor categories. Other airport-specific and location-specific factors include local and national cost and/or availability of materials, local inflation and unemployment rates, and specific bonding requirements as well as the associated costs of procuring such bonds.
- **Estimate the cost of each subsystem or element of the APM system based on normalized historical data.** Breaking the estimated costs down by system and major subsystem facilitates the comparison, possible negotiation, and the reconciliation of estimated costs with the proposed actual costs. Within the APM industry, there are fairly standardized breakdowns for both system estimates and the supplier's proposed costs. Although the total scope of these breakdowns is beyond the scope of this guidebook, the following are some major, industry-accepted breakdown categories: guideway facilities; station facilities; maintenance and storage facility; power distribution facilities; command, control, and communication facilities; fixed facility verification and acceptance; infrastructure and sitework; equipment rooms and UPS spaces; guideway equipment; station equipment; maintenance and storage facility equipment; power distribution system equipment; command, control, and communications equipment; vehicles; operating system verification and acceptance; and project management and administration.
- **Include contingency, soft costs, and inflation/escalation to determine systems cost estimate.** The total capital cost estimate will include factors such as contingency, escalation, and overhead and profit, in addition to soft costs that are associated with the design and construction management of the APM system. These factors are best determined and applied on a local and project-specific basis. Whether such factors are applied "above the line" or "below the line" in terms of labor and material subtotals is also best determined by the typical practices of the specific location and project.
- **Estimate facilities costs using quantity takeoffs.** As discussed in the introduction to this section, the fixed facility costs may be assigned to a conventional cost estimating entity; estimating the cost of the APM fixed facilities does not require any specialized expertise once the facilities are designed. However, it is recommended that an entity with experience in the APM industry coordinate with the cost estimator to ensure that any APM-specific issues are adequately addressed.
- **Determine system versus facilities procurement packaging and its impact on supplier competition.** Within the APM industry, there are a variety of ways APM systems and associated fixed facilities can be procured; various methods are discussed in Chapter 10. Many procurement options exist, and the best approach should be determined by a specific procurement plan agreed to by all appropriate parties in accordance with local, state, and national law. Such a procurement plan is most appropriately developed after the planning stage of the system and is thus beyond the scope of this guidebook. However, general assumptions regarding the procurement approach, particularly with regard to packaging different contracts, are appropriate to consider when estimating the cost of planning the APM because such packaging can affect supplier competition and price. Such factors should be considered in how the total work is packaged in terms of stand-alone contracts or contracts requiring a combination of construction trades. For instance, it would not be unusual to include the construction of the power distribution substation building as part of the contract that constructs the APM stations since both involve the same building trades. In addition, such packaging should be considered in conjunction with local practice and project-specific issues such as minority, women, and disadvantaged business enterprise (M/W/DBE) participation goals.

Cost–Benefit Analysis

At this point in the planning process, it is assumed that the proposed APM system's level of service has been checked for

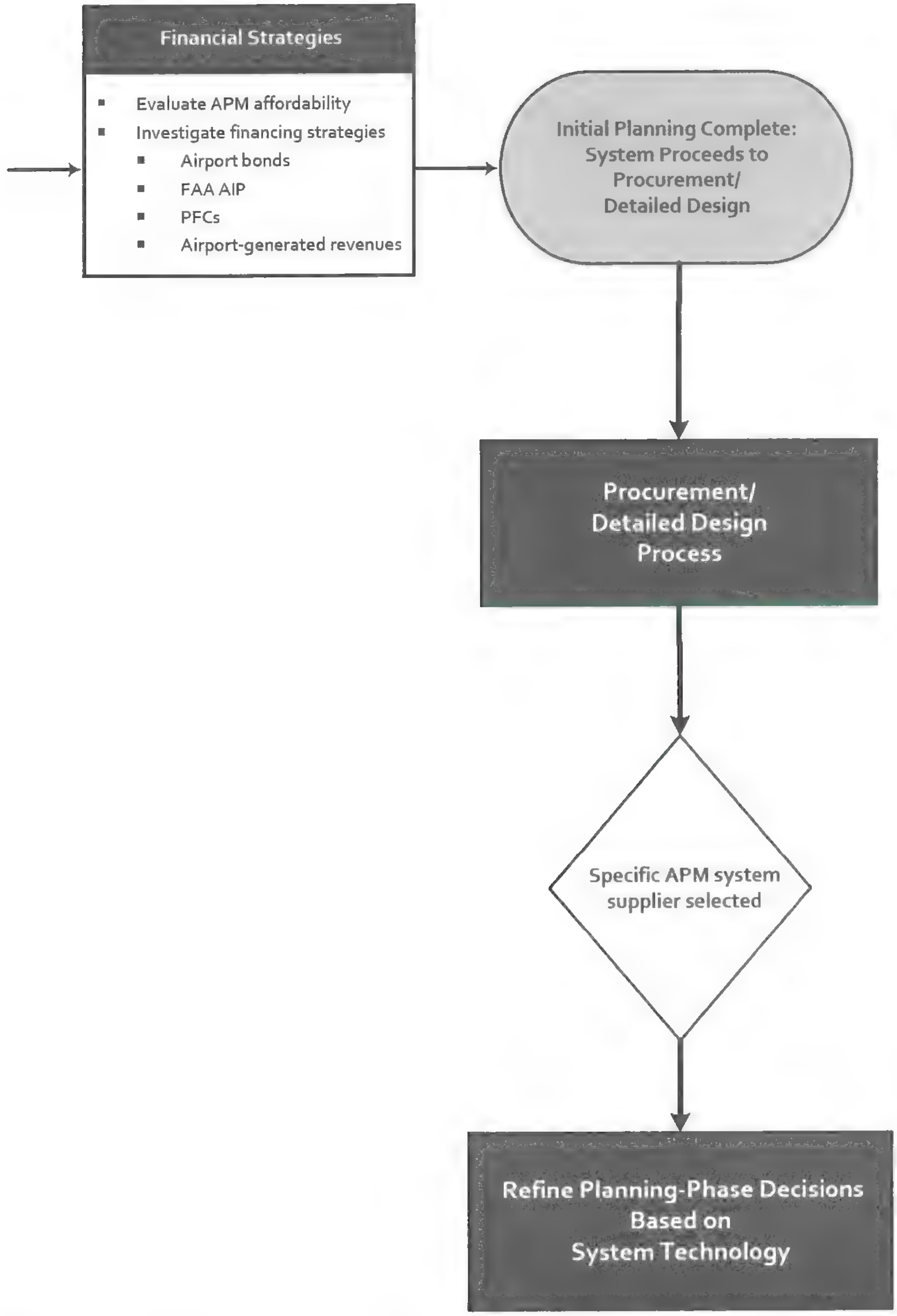
any fatal flaws in meeting the airport's goals and objectives and that complete O&M and capital cost estimates have been produced for the subject system. The next recommended step is to look at those costs in terms of a cost–benefit analysis. Detailed information regarding performance of a cost–benefit analysis for an airport APM is presented in Section 9.2.

- **Identify a base case (no-build alternative) and an evaluation period over which to measure costs and benefits.** The base case, no-build alternative must be evaluated over a period of time. The length of this time period should be commensurate with other projected time frames within which milestones affecting the airport will occur. For example, within what time frame is a particular percent increase in airport operations projected to occur? Within what time frame are a certain number of aircraft gates projected to be required? Within what time frame is a new concourse or terminal projected to be built? The no-build base case should be evaluated within such time frames.
- **Measure and compare the costs and benefits for the airport, its passengers, and the general public if the APM is built and in the no-build base case.** Some benefits that can be compared are directly related to level-of-service issues affecting the airport's passengers and general public. Such issues may include travel time, walk distance, ease of wayfinding, work effort, and comfort and/or protection from the elements. For an airside APM serving an airline hubbing operation, the benefits are more airline-focused and can translate directly into increased revenue through increased number of daily/annual flights at the airport. Refer to Section 9.2 for more details.
- **Evaluate the accuracy of the cost–benefit analysis and then determine whether or not the benefits outweigh the costs and the system should be built.** The cost–benefit analysis will include some subjective criteria that are not as easily evaluated as objective data such as hard costs. Subjective data can be ranked, weighted, and empirically analyzed in a way that offers a fair, impartial, and accurate assessment and comparison. The parties charged with decision making should assure themselves that the cost–benefit analysis is accurate in terms of both subjective and objective data and base their ultimate build/no-build decision on this.

The reader is encouraged to note Figure A-5 where the airside system has been determined to have connectivity benefits that outweigh its cost.

Financial Strategies

- **Evaluate APM affordability.** Now that the APM system planning has been approved, its overall affordability must be assessed as part of the airport's projected capital program. This is illustrated graphically in the Figure A-6 flowchart. At this point, several options can be considered depending on the particular financial situation of the airport. If adequate funds exist, the entire system would likely move forward toward procurement and implementation. Another option would be to phase in the implementation of the system in order to extend cash flow requirements. Note that this approach, although not uncommon, results in cost deferment, not cost savings, and the final cost for full system implementation is invariably greater due to inflation factors.
- **Investigate financing strategies.** Different financing strategies are airport-specific and depend upon a variety of factors, including whether the airport is functionally a department of its host city or is controlled by an independent quasi-governmental body. This and other differences play a role in how the particular airport's rates, fees, and charges are assessed and managed. The following are examples of some of the more common funding avenues for airside APM systems although they may not apply to the particular airport at hand.
  - **Airport bonds.** Such bonds may be joint revenue bonds where debt service is shared widely among all airport stakeholders. In addition, airports may issue special facility bonds where the debt service is assigned to a single entity, such as an airline, or a small pool of users. Special facility bonds are typically used to fund dedicated-use projects where the project's use is virtually exclusive to the bond guarantor.
  - **FAA Airport Improvement Program.** The AIP is a federal grant program with funding generally provided via two categories: entitlement funds and discretionary funds. Either of these funding types must meet certain prerequisite requirements (grant assurances) established by the FAA. Eligible projects are those that enhance safety, security, or capacity or mitigate environmental concerns. Ineligible projects are those related to the airport's operations, including maintenance. An APM system's capital cost would typically qualify for this funding type, whereas the system's O&M costs would not be eligible.
    - **Passenger facility charges.** Most major U.S. airports collect a PFC, which is a fee added to the cost of the ticket for each enplaning passenger. The amount per ticket can vary, at the airport's discretion, and has increased from a maximum of \$3.00 per ticket when Congress approved PFCs in 1992 to a current maximum of \$4.50 per enplaning passenger. PFCs fall under the jurisdiction of the FAA and, similar to AIP funding, must be used for projects that enhance safety, security, or capacity, reduce noise, or increase competition between air carriers.



Source: Lea+Elliott, Inc.

Figure A-6. Final APM planning process.

- **Airport-generated revenues.** Assuming such revenue is specifically self-generated by the airport, this funding typically has the fewest restrictions of the funding examples presented. Airports have multiple self-generated revenue streams, the largest of which being landing fees, concession and other lease agreements, and parking fees. Other airport-generated revenue may be tied to the specific development opportunities of the particular airport. For example, DFW International Airport was able to generate a substantial revenue stream by negotiating on-airport drilling rights with natural gas drilling companies.

The reader is encouraged to note the final decision diamond and process boxes in the Figure A-6 flowchart where the planning for the theoretical airside system has been completed with the system moving into the procurement and detailed design phases. Of particular note is the fact that once a specific APM technology is selected, it is often necessary to revisit and refine some of the planning decisions.

At the end of this appendix, a number of underground, airside APM alignments are provided as examples of the type of system that has emerged from the APM planning process described above. For specific details on these existing airside APMs, please see Appendix B.

Example 2: Planning a Landside Shuttle APM System

For this discussion, refer to the Figure A-7 flowchart, Summary Landside APM Planning Process. This discussion follows this summary flowchart and the subsequent, more-detailed flowcharts; italicized notes provide cues for the reader to refer to specific aspects of the flowcharts.

For Example 2, the first more-detailed flowchart (Figure A-8) commences with stating the principal need: "Airport wants to improve landside mobility by providing access to parking and regional rail via an APM." As discussed briefly in Example 1 for the airside APM system, there are different reasons justifying the implementation of a landside APM system than there are for justifying an airside APM system. This is because, over time, the airport's physical facilities can grow to a point where the physical distances between connecting gates become too great to be traversed by means other than an APM or the physical location of connecting gates may virtually dictate an airside APM system. For landside systems, no such thresholds typically exist that are as compelling for the implementation of an APM. Instead, landside APM systems are more commonly justified by:

1. Level-of-service issues in accessing remote airport facilities. Such facilities may be inherently remote (such as remote employee parking) or may have been moved from the central terminal area (CTA) to a remote location (such as a remote consolidated rental car facility) in order to free the CTA location for a higher and better use.
2. Service to multiple facilities. The benefit of a landside APM increases as the number of facilities that it serves increases. The type of facilities served by the landside APM may be symbiotic in their similar functions or may be stand-alone facilities. Regardless, a landside APM can serve as a consolidating factor, strengthening the viability of all such facilities by physically linking them together.

The assumptions for this appendix state that an APM has already been selected over alternate systems, but a further assumption of Example 2 is that the landside APM system inherently has a significantly higher level of service than alternate systems such as a busing system, although it may have an appropriately lower level of service than the Example 1 airside APM system.

Operational Considerations

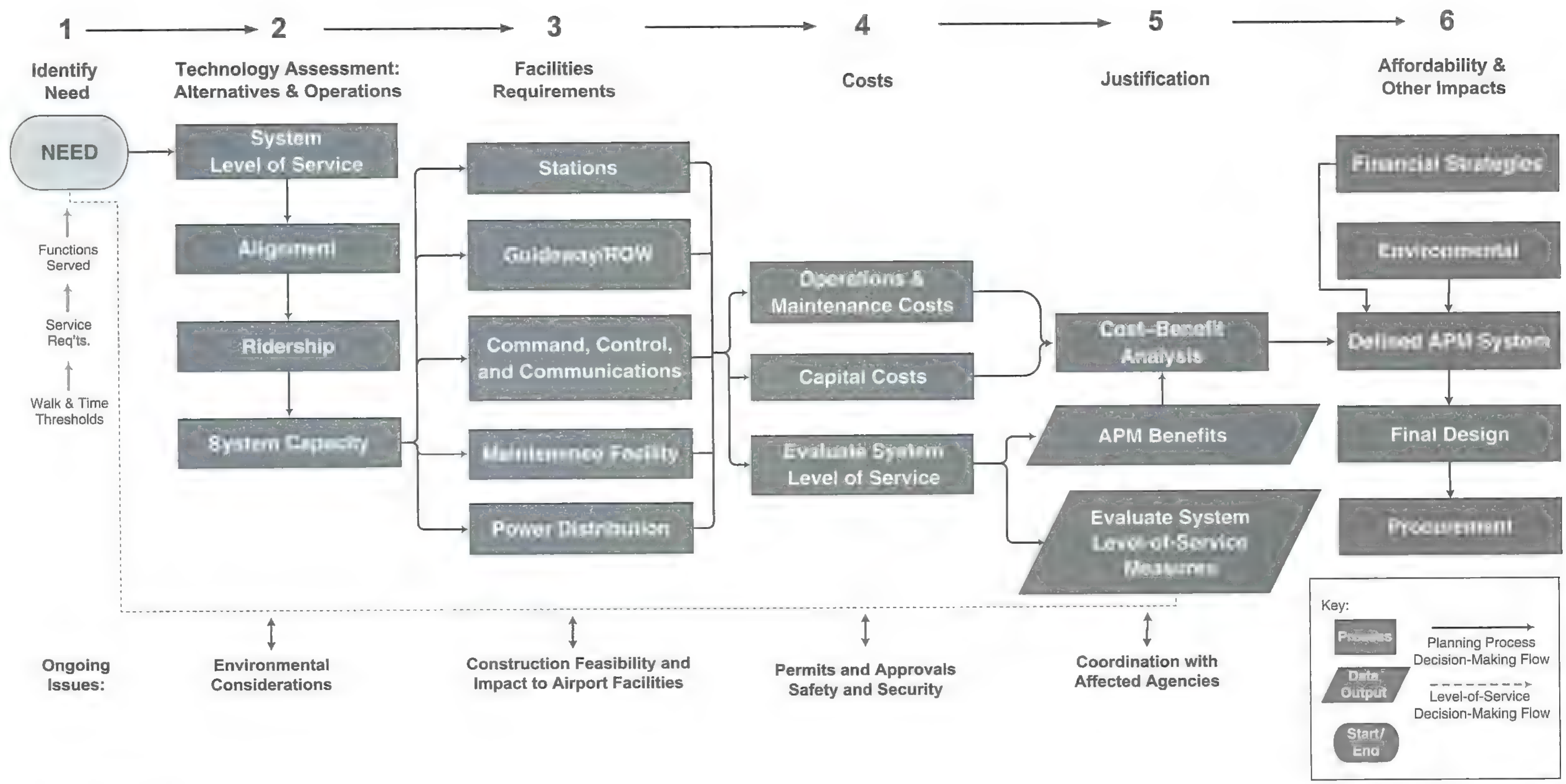
A prerequisite for the successful planning of a landside APM is to embrace the presumption to plan the system around project-specific operational considerations and not to plan the system around a specific APM technology and its characteristics. The following discussion amplifies the operational considerations listed in the process blocks of the flowchart.

System Level of Service

- **Determine the level-of-service priorities based on the airport's goals and objectives.** One may initially assume that all APM systems should strive to be designed to offer the highest level of service possible. However, this is not necessarily the case with landside systems. For example, comparatively longer headways may be acceptable and appropriate for a landside APM system than for an airside system. This is because a landside system typically lacks the critical time windows that must be met by an airside system. While an inbound landside passenger may have to catch a plane, the passenger's arrival time and lead times at the airport are self-determined, not pre-determined by the airline, as are the airside passengers' connection times. Although some landside systems are must-ride systems in terms of distances or lack of a pedestrian right-of-way, they are typically easier to provide a temporary backup system (such as buses) for than are the airside must-ride systems. Thus, a landside system's redundancy and failure management modes may not be as critical as those of an airside system.

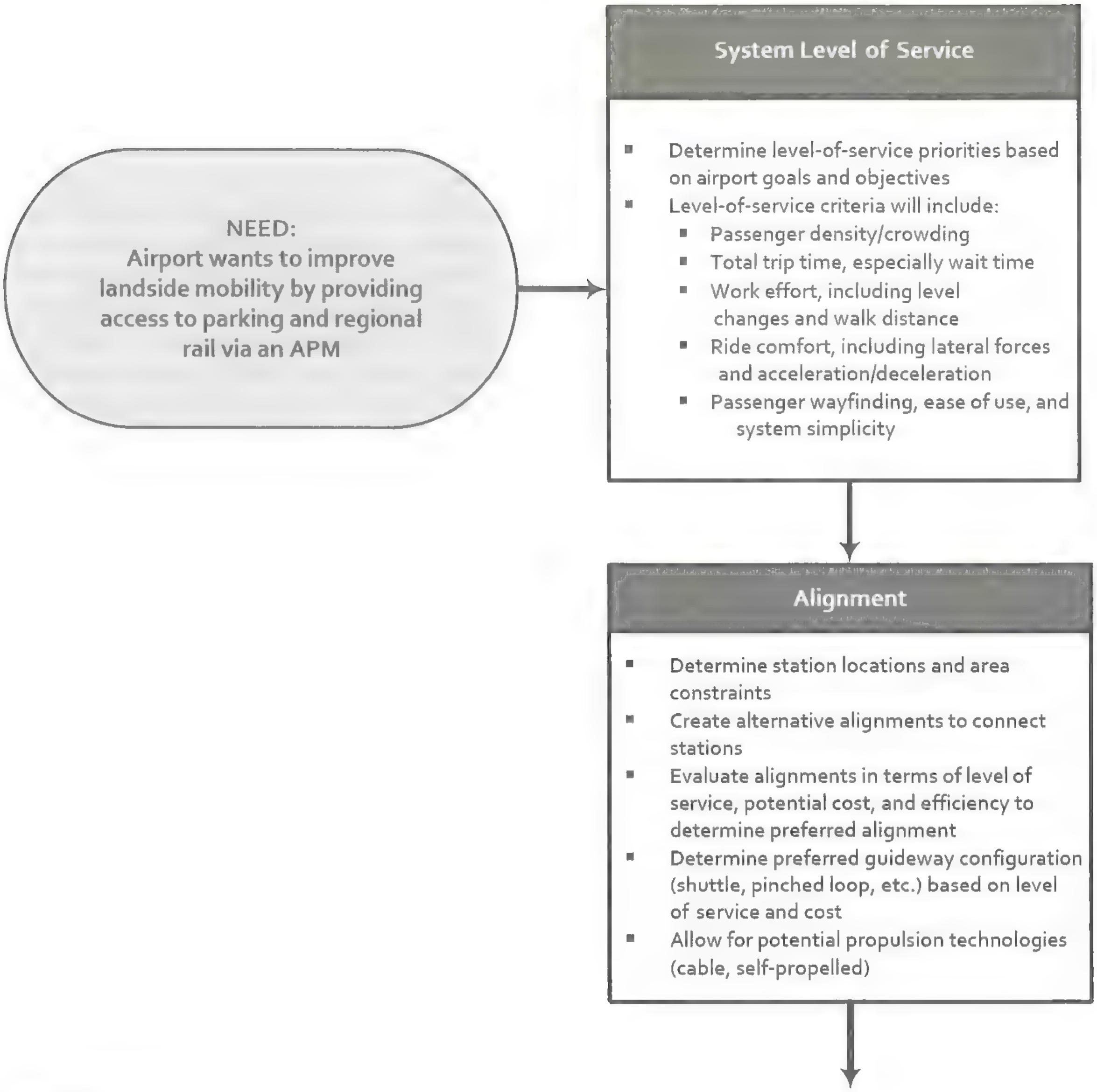
  Other landside level of service planning criteria include:

- **Passenger density and crowding.** Landside passengers that have landed at their destination airport will choose to stop boarding a train when their perception is that the train is full. Thus, although it is not possible to purposely plan to crowd passengers onto a train, certain planning parameters can result in different levels of density and crowding on the station platform. As such, it should be decided what amount will be acceptable from a planning standpoint. The options for landside systems may be somewhat less stringent than for airside systems serving connecting airline passengers.
- **Passenger effort, including level changes and walk distance.** A generally accepted planning assumption is that fewer level changes are desirable because level changes not only increase passenger effort (even with escalators) but



Source: Lea+Elliott, Inc.

Figure A-7. Summary landside APM planning process.



Source: Lea+Elliott, Inc.

Figure A-8. APM operations planning process.

also decrease wayfinding clarity. A generally accepted planning assumption is that less walk distance is desirable. This is equally true for both landside and airside APM systems. In the United States, walk distance is defined as the distance the passenger actually walks, not the distance the passenger travels (while standing on moving walkways for example). Outside the United States, planners sometimes assume that passengers walk on moving walkways.

- **Ride comfort, including lateral forces and acceleration/deceleration.** Such forces are typically specified in terms of allowable maximums set by pre-established industry standards. These standards exist not only for comfort but also for safety. However, exceptions may be made in certain cases. For example, when particular guideway alignment options dictate a vertical grade beyond normal practices, certain ride comfort factors will be degraded.
- **Passenger wayfinding, ease of use, and system simplicity.** A generally accepted planning assumption is that simplicity in wayfinding is desirable. Specifically, minimizing the number of decision points that the passenger must make is desirable. All APM systems require audio and visual (signage) cues because they typically require self-use by the passenger, without attendants.

Alignment

- **Determine station locations and area constraints.** Planning for the number, spacing, and placement of landside

APM stations should strive to provide the maximum convenient service to the largest range of users with the fewest possible number of stations. Planning for the fewest practical number of stations needed to provide the appropriate level of service helps the economy and efficiency of the system in terms of fleet size and reduces the capital and O&M costs of both the APM system and the associated fixed facilities. However, from a planning standpoint, if the landside system is being retrofitted to serve existing facilities, station locations may essentially be predetermined by the location of such facilities.

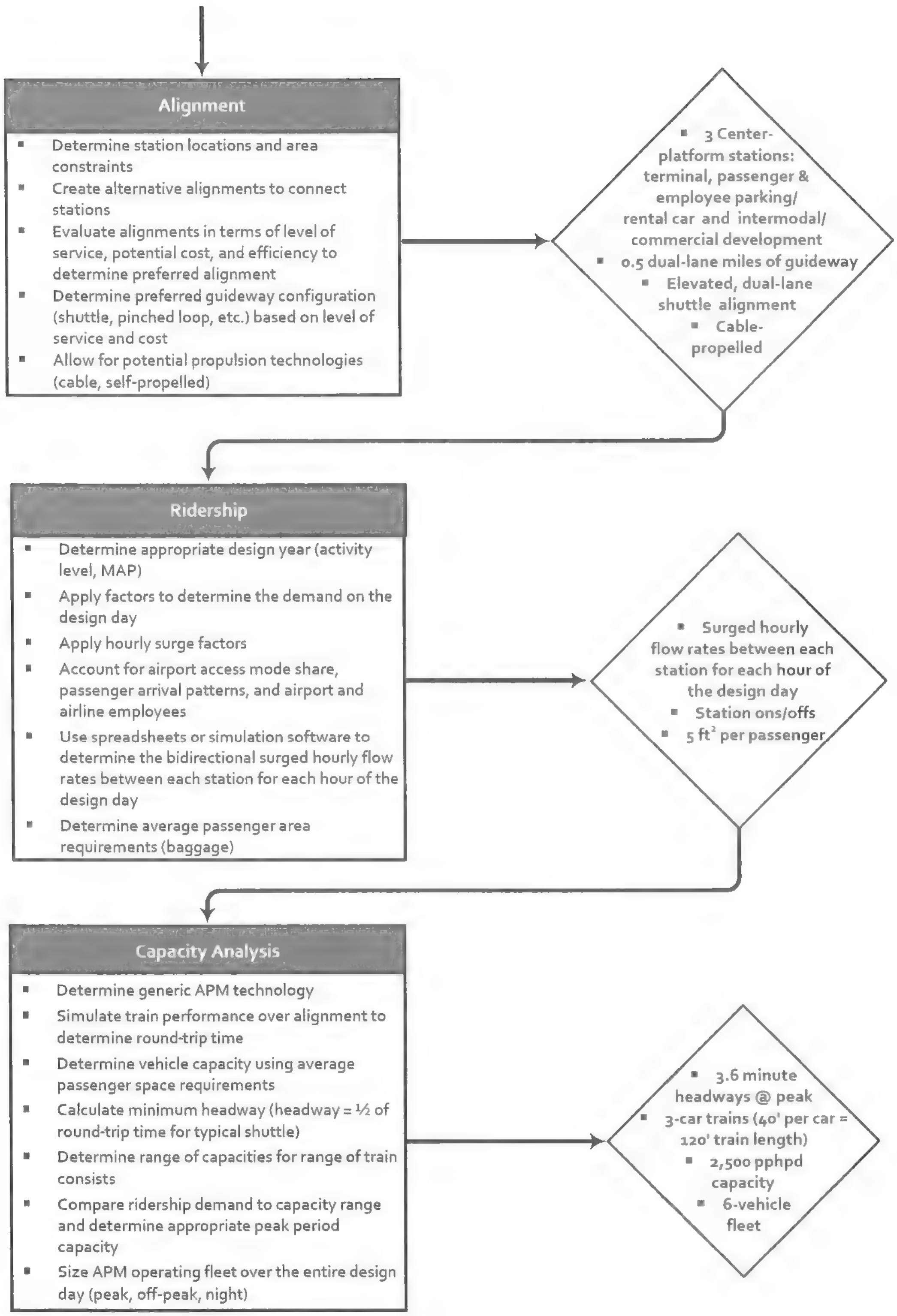
- **Create alternative alignments to connect stations.** The actual guideway alignment is a means to an end. The end is to serve the stations that have been located to meet various project-specific parameters. The most efficient guideway alignment is one that is perfectly straight and perfectly level, but in real-world planning it is seldom possible to provide such a guideway, particularly when introducing an APM into an existing airport's landside environment. However, there is typically an optimal geometrical guideway alignment to connect the planned stations, and the most effective way to determine such an alignment is to explore many different ones.
- **Evaluate alignments in terms of level of service, potential cost, and efficiency to determine preferred alignment.** Using the different alternate alignments that have been developed, consider how the level of service, cost, and system efficiency are affected by the specific differences in the alternatives. These differences may include aerial versus subgrade and/or combinations of aerial and subgrade alignments. Aerial alignments are typical for landside APMs. Additional areas for evaluation include the alignment's impact on existing facilities, impact on future growth potential, ease of expandability, and the ease and/or possibility of phased implementation and/or expansion. Specifics regarding the configuration of the alignment should also be evaluated, particularly for associated cost implications.
- **Determine preferred guideway configuration (shuttle, pinched loop, etc.) based on level of service and cost.** In parallel with the exploration of various guideway alignments, various configurations of the guideway should also be developed at a conceptual level. For instance, a two-way loop configuration may provide the needed level of service, but further exploration may reveal that a pinched-loop configuration provides an equal level of service yet gains an economic advantage by not needing the construction of as long a guideway. While the length of landside APM systems varies greatly, for the shorter systems connecting the main terminal to a single garage or rental car facilities, the system length and system frequency requirements may be such that a dual-lane shuttle with just two trains operating (one on each lane) is sufficient to meet the capacity needs of the system.
- **Allow for potential propulsion technologies (cable, self-propelled).** Some aspects of a guideway's alignment have differing effects on different propulsion technologies. For instance, LIM propulsion is typically more sensitive to grades. Also, certain cable technologies are more sensitive to vertical curves (particularly concave, or sagging, vertical curves) because the cable may lift from the sheaves in certain instances. More detailed design analysis is required to confirm and/or solve such specifics, but the planner should be aware of such issues even in the early planning stages of the APM. As noted in the guideway configuration paragraph above, the resulting dual-lane shuttle could accommodate either a cable- or a self-propelled technology. For the purposes of this example (and to differentiate from Example 1) it is assumed that a cable-propelled technology would ultimately be selected. Good planning practice ensures that both cable- and self-propelled technologies can be accommodated to provide maximum supplier competition and the best price and value for the airport.

The reader is encouraged to note the decision diamond in Figure A-9 where the theoretical landside system has now been planned as an elevated, cable-propelled dual-lane shuttle with 0.5 miles of dual-lane guideway and three center platform stations. The APM will connect the terminal, passenger and employee parking, rental car facilities, and an intermodal/commercial development area. The decisions reached for this theoretical example (elevated, cable, shuttle, etc.) are common decisions found in actual landside APM systems. Specific decisions at each airport depend upon the site-specific environment. Reasons for the decisions in our theoretical example might be as follows:

- *Elevated–Landside APMs are in a more cost-sensitive environment competing against buses on an existing roadway system (compared to an airside APM), and therefore underground construction is ruled out. At-grade systems are also difficult to fit in to an existing airport landside environment, and therefore an elevated structure is typically chosen.*
- *Cable and shuttle—As stated above, landside APMs are elevated in a cost-sensitive environment. They are often shorter systems, accommodated by cable-propulsion and dual-lane shuttle operations, and provide the necessary level-of-service performance as opposed to longer systems that would cost more and require self-propelled/pinched-loop systems.*

Ridership

- **Determine appropriate design year (activity level, MAP).** The landside APM should be planned for implementation at a time when ridership demand warrants it, and this threshold may be tied to the airport's overall master plan and activity level projections in terms of MAP or other projected levels



Source: Lea+Elliott, Inc.

Figure A-9. APM capacity planning process.

of passenger activity or facility implementation. Specific future projects, such as a planned landside hotel, a consolidated rental car facility, a light rail intermodal station, or other landside projects may trigger when an APM is warranted.

- **Apply factors to determine the demand on the design day.** Ultimately, the ridership demand analysis for a landside system must determine how many people need to go where and when. Many of the factors such as walk speeds, distances, flow capacities, and vertical circulation capacities are the same as for airside systems. However, such factors may vary more for landside systems because the served facilities and passenger population groups are typically more diverse than for airside systems, which primarily serve passengers making online connections.
- **Apply hourly surge factors.** Surge factors represent a case where a landside system may have more variation than an airside system. Surge factors account for a particular surge of riders above the average ridership that must be planned for and accommodated by the system. For airside systems, surges are typically a result of hub airline complexes (times that a large number of aircraft arrive, passengers transfer between aircraft, and when the aircraft depart). Surge factors for a landside system may be generated by a greater variety of causes and thus have greater variation over different time intervals. Surge factors for landside systems are typically more project specific than for airside systems, and as such, require more research and analysis.
- **Account for airport access mode share, passenger arrival patterns, and airport and airline employees.** These factors constitute inputs for spreadsheets or simulation programs necessary to determine the landside ridership demands. These factors are more variable for landside systems than airside systems and require expert project-specific research and analysis. This is inherently due to the wide range of types of facilities and functions that can be served by a landside APM. For instance, a landside system planned for a coastal airport may have airport–seaport transfers as a primary ridership component, whereas an inland landside system would not have this ridership component at all.
- **Use spreadsheets or simulation software to determine the bidirectional surged hourly flow rates between each station for each hour of the design day.** This is a specialized task that involves calculating the ridership volumes between each station, the number of passengers deboarding and boarding at each station, and the system's peak link. As noted, in addition to the design hour of the design day, ridership is typically analyzed and determined for a variety of off-peak hours in order to accurately estimate how the APM system will operate throughout a typical 24-hour period.
- **Determine average passenger area requirements (baggage).** This varies by project, particularly between airside and landside systems. Passenger area requirements are expressed as an area for each standing and seated passenger, respectively. In the case of the theoretical landside system, it is assumed that passengers will be in possession of all of their baggage (carry-on as well as checked), and the space per passenger should be calculated accordingly. Such space is typically more than for an airside system, which must accommodate only carry-on baggage. Airports typically collect baggage characteristics of their passengers through on-airport surveys, which can be used for the APM analysis.

The reader is encouraged to note the decision diamond in Figure A-9 where the theoretical landside system has now been planned for particular surged hourly flow rates between stations for each hour of the design day with a known number of deboardings and boardings at each station and 5 square feet per person allocated within the vehicles.

Capacity Analysis

- **Determine generic APM technology.** The actual technology of an actual APM supplier is not assumed for this step. Rather, the planner should determine/develop a generic APM technology that is generally representative of several actual APM suppliers. This will help ensure healthy competition among multiple suppliers may ultimately provide a system in accordance with the performance specifications to be developed during the subsequent design phase. An example involving this generic APM technology would be the assumption of using a generic 40-foot vehicle because many APM suppliers produce a vehicle close to a 40-foot length.
- **Simulate train performance over alignment to determine RTT.** This typically requires the use of specialized computer modeling in all but the most simply configured APM systems and again should best be assigned to an entity with experience in this specialized field.
- **Determine vehicle capacity using average passenger space requirements.** In this planning task, the generic 40-foot vehicles can be assumed to accommodate a certain number of standing and seated passengers based upon the planned 5 square feet per passenger for the theoretical landside system.
- **Calculate the minimum headway (headway = ½ of round trip time for typical shuttle).** This calculation is self explanatory and considerably simpler than for the airside system in Example 1 because the theoretical landside system is being planned as a dual-lane shuttle with two trains operating in a synchronized manner. However, in real world planning, landside systems may be planned for a variety of configurations, not only a dual-lane shuttle. As such, a train performance model should be utilized. This should be done by a party with experience in this type of simulation.

- **Determine range of capacities for range of train consists.** For this planning task, a variety of APM performance criteria must be considered jointly in order to ensure that the most efficient system is developed, just as in Example 1 for the airside system. However, in the case of this dual-lane shuttle landside system, train consist becomes primarily related to future expansion needs. This is because the dual-lane shuttle system is limited to two trains—one per lane—and future capacity expansion can only be achieved by adding vehicles to these two trains.
- **Compare ridership demand to capacity range and determine appropriate peak-period capacity.** This task determines the peak link during the peak period of demand. The peak link is defined as the link between stations that has the highest ridership demand. Although other links between stations will have less ridership demand, it is the single peak link that drives system capacity.
- **Size APM operating fleet over the entire design day (peak, off-peak, night).** Because ridership demand varies over the day, the capacity of the APM system should be adjusted to match demand to the greatest degree that is possible. With the landside dual-lane shuttle, such options are limited to running either one or both trains, as well as to possible on-call operational modes. Typically, with a dual-lane shuttle, both trains are operational during peak hours. During off-peak night hours, only one train is operated, which allows maintenance on the non-operating train as well as wayside maintenance of the inactive guideway lane. Such downtimes are typically rotated each night between the two trains and their guideways. An on-call mode may be used during off-peak hours where the single operational train idles in a berthing position at one of the stations until it is called into service via passenger-sensing motion detectors in the stations or by passenger use of elevator style call buttons in the stations.

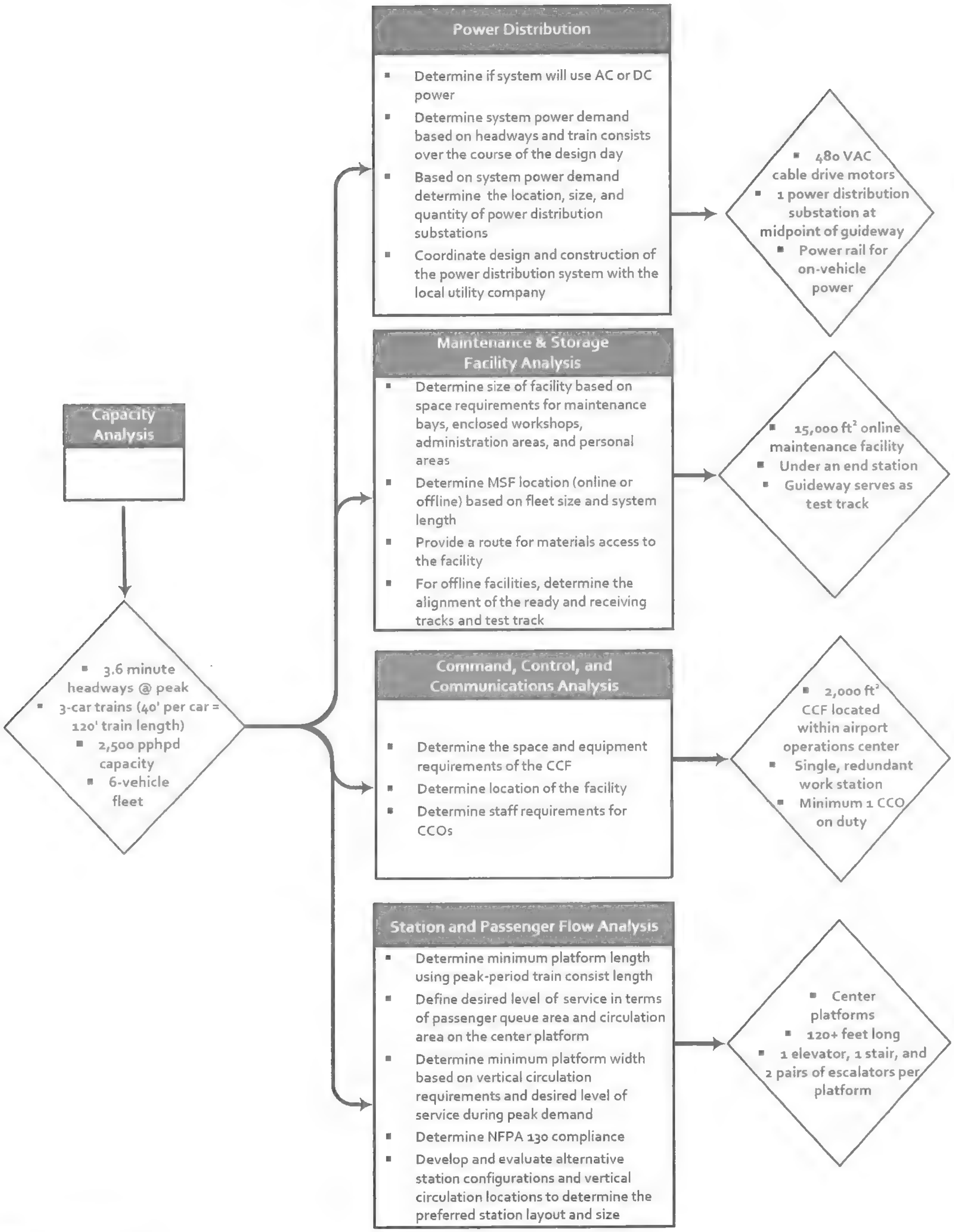
The reader is encouraged to note the decision diamond in Figure A-9 where the theoretical landside system has now been planned for a six-vehicle fleet consisting of two three-car trains with 40-foot vehicles resulting in 120-foot train lengths running at 3.6 minute peak headways resulting in a capacity of 2,500 pphpd.

Technical Considerations

The successful planning of an APM also involves consideration of technical aspects of the system. Each APM system is proprietary and is therefore unique with regard to many particular technical aspects. The challenge to the APM planner is to appropriately plan the system in accordance with known technical considerations, yet not to a degree so specific that certain suppliers are unable to provide a viable system. This increases competition, which is in the best interests of the airport. The following discussion amplifies the technical considerations listed in the process blocks of Figure A-10.

Power Distribution

- **AC or DC propulsion power distribution?** Although the actual onboard traction motors that propel APM vehicles are universally AC, the propulsion power distribution system that provides the guideway power to the vehicles along the guideway may be AC or DC, depending upon the particular supplier. While there are advantages and disadvantages to each, from a planning perspective it is not useful to assume one is better than the other or to attempt to predict which will be used. Rather, it is important for the planner to understand the differences between the distribution systems that affect the planning of the system. For instance, power distribution substations for a DC system can be located further apart than those of an AC system. More and larger equipment within the substation is required for DC systems. Thus, substation space requirements will be greater for DC systems. DC ground current is of greater concern than that of AC and may require corrosion control measures and current testing facilities that are not required for AC systems. For the landside system in this example, cable propulsion has been chosen. For planning purposes, all cable systems can be assumed to use AC power to the drive machines that move the rope (cable) that ultimately moves the trains. The trains of a cable-propelled system are passive in terms of propulsion power, but do have onboard housekeeping electrical requirements for lighting, HVAC, and communications. Thus, there is power distribution along the guideway of a cable system, albeit not propulsion power; this power is also AC.
- **Determine system power demand based on headways and train consists over the course of the design day.** The system's power demand will be used in O&M budgetary planning by the airport and will also be needed by the local utility company, which will provide the high-side power to the APM system. The power demand may be manually derived for small systems, but computer modeling of power demand is virtually essential for larger systems with multiple trains and changing train consists.
- **Based on system power demand, determine the location, size, and number of power distribution substations.** This is where some of the differences in planning for an AC or a DC system will come into play. However, regardless of AC or DC power distribution, some general planning rules are applicable. Generally, the substations should be located directly adjacent to the guideway if possible. If multiple substations are required, their general locations should be located equidistantly along the guideway, and equidistant from each other to the degree possible, in order to minimize voltage drops and increase efficiency. Each substation



Source: Lea+Elliott, Inc.

Figure A-10. APM technical planning process.

will require access for equipment and personnel, including on-site parking and loading areas. Housekeeping power to the substations must also be planned. For the subject landside APM system, cable propulsion has been assumed, and thus planning for power distribution is somewhat simplified compared to an airside system as there is no need for multiple power distribution stations located along the wayside of the guideway. Instead, all propulsion power equipment is typically located in a single facility adjacent to the cable drive equipment.

- **Coordinate design and construction of the power distribution system with the local utility company.** This task involves coordinating the layout of the physical aspects of the power distribution system. For instance, the local utility company may provide and install the power service entrance or what is sometimes referred to as the distribution yard. In addition, other design aspects of the distribution system must be coordinated with the local utility company. For instance, regenerative braking enhances energy efficiency by capturing braking energy and feeding it back to other trains or back to the utility. However, some utility companies will not allow this. AC systems are more likely to induce harmonic noise on the utility distribution lines. This may require harmonic filtering, and this should also be coordinated with the utility company.

The reader is encouraged to note the decision diamond in Figure A-10 where the landside system in this example has now been planned for two 480 VAC drive motors, with one motor powering each guideway lane individually.

Maintenance and Storage Facility Analysis

- **Determine size of facility based on space requirements for maintenance bays, enclosed workshops, administration areas, and personnel areas.** For shuttle systems such as the landside system in this example, the MSF is typically online because the trains are never removed from the main guideways for maintenance. For larger pinched-loop systems, the MSF is offline, as described in Example 1. Although the MSF houses a specialized function, architectural and engineering firms require no specialized expertise to design and produce the construction documents for the MSF once it is programmed. However, it is this architectural programming that is critical to the success of the MSF.
- **Determine maintenance facility location (online or offline) based on fleet size and system length.** Online maintenance facilities are typically located directly beneath a station if the system employs an aerial guideway, or directly adjacent to a station if the system is below grade. This is due primarily to architectural and functional efficiency. However, some existing shuttle systems have an online MSF located between stations, and from a planning perspective, the exact location for an online MSF is best determined in consideration of project-specific parameters. APM maintenance facilities are unlike a bus maintenance facility in that they are clean and quiet because internal combustion engines are not involved. Thus, from a planning perspective, the MSF may be located in sensitive areas, such as within an airport terminal building, without any negative impact.
- **Provide a route for delivery of materials to the facility.** This includes site access that can accommodate trucked deliveries, including full-size tractor-trailers on occasion. A route for material delivery applies not only to the siting of the MSF but to circulation within the facility itself. Planning should dimensionally accommodate a forklift with pallets in and around all maintenance bays, including a path to parts storage or other accessed areas. Planning should accommodate delivery and storage of items that dimensionally will not fit within a freight elevator. One example is replacement power and signal rail, which typically comes in 40-foot lengths.

The reader is encouraged to note the decision diamond in Figure A-10 where the theoretical landside system has now been planned to include a 15,000 square foot online maintenance facility located underground at the end (parking) station. The guideway mainlanes will serve as test tracks when needed.

Command, Control, and Communications Analysis

- **Determine the space and equipment requirements of the central control facility.** The size and layout of the CCF varies somewhat in proportion to the size of the APM system. However, all CCFs have basic requirements that must be planned for. These include the control console with system mimic screens, and CCTV monitors for station (and possibly other) surveillance, all within sight of the central control operators. Typically, an APM equipment room is located directly adjacent to the CCF. The specific requirements for the equipment and layout of the facility must be considered to ensure that an adequate spatial footprint is reserved in the planning stage. The CCF should be planned to accommodate additional equipment and/or personnel required for future expansion of the system, if such expansion is anticipated. With regard specifically to the landside system in this example, such CCF expansion considerations are probably not applicable because a cable-propelled dual-lane shuttle is difficult to expand in an economical or practical way. Such expansion is not impossible, but if it is an important planning consideration, a self-propelled dual-lane shuttle would be a better planning choice.
- **Determine the location of the facility.** From a planning perspective, combining the CCF with the MSF (locating the CCF within the MSF) is typically a solution that allows

functional consolidation and efficiencies. If the CCF is located remotely from the MSF, some duplication of minimum essential facilities such as restrooms and administrative space may be required. The initial location planned for the CCF should be considered its permanent location, and any possible expansion or changes to adjacent or surrounding facilities that could cause disruption to the CCF should be considered when choosing this location. Although CCFs have been successfully relocated, the CCF is the electronic center of the APM system; thus, such relocations are difficult, expensive, and invariably cause significant operational disruptions.

- **Determine staff requirements for central control operators.** Adequate staffing and the number of CCOs should be considered with project-specific requirements. As a general planning rule, a minimum of two CCOs should staff the CCF at any time. The total number of CCOs will depend upon system size, shift arrangements, and benefit (particularly leave) factors.

The reader is encouraged to note the decision diamond in Figure A-10 where the theoretical landside system has now been planned to include a 2,000 square foot CCF located within the airport operations center with a single redundant workstation and a minimum of a single CCO on duty.

Station and Passenger Flow Analysis

A prerequisite note regarding the following bullets is that architectural analysis and programming is critical to the successful planning of the stations. Also, reference Section 8.4, Stations, for additional detailed discussion regarding the programming of APM stations.

- **Determine minimum platform length using maximum train consist length.** Various queuing areas for passengers must be taken into account when the total platform length is determined. These include queues for the trains as well as for escalators and elevators. If future expansion plans call for increasing the number of vehicles per train, then the platform must be sized to accommodate this future train length. In these cases, the automatic station doors for the future vehicles are typically not installed, although their positions are reserved by removable window wall assemblies or some type of removable panels. In some instances, the future automatic station door sets may be procured and installed prior to their actual activation.
- **Define desired level of service in terms of passenger queue area and circulation area on the center platform.** This level of service can range from planning for virtually no waiting queue to, in rare occasions, missed trains being an acceptable situation during peak periods. The queue area depends upon the headways of the trains to a large degree, and thus should be planned in conjunction with the trains' performance parameters. The circulation on an APM platform requires circulation paths to and from the trains and to and from vertical circulation elements. Few if any other functions typically exist on the platform. For instance, it is not recommended to install seating, vending machines, newspaper racks, telephone banks, FIDS, or other such amenities on an APM platform. The short wait times on the platform do not permit use of such amenities without interfering with the primary purpose of the platform, which is to quickly and efficiently move people on and off the trains.
- **Determine minimum platform width based on vertical circulation requirements and desired level of service during peak demand.** This is another topic for which the reader is encouraged to review Section 8.4, Stations, for additional detailed discussion. As an overview, the minimum platform width for small APM systems (i.e., a short landside shuttle) may likely be determined by the minimum width required for the vertical circulation elements. Assuming all of these elements would be grouped at one end of the station, their combined dimensions would constitute the minimum possible width of the associated platform. Also, the type of station is a key factor in determining minimum platform width(s). For example, a center platform station has a single area that must accommodate two functional platforms for trains arriving on either side. This single platform accommodates both boarding and deboarding passengers, and the fact that two trains may arrive at the same time (for example, at the middle station of a three-station shuttle) must be considered. Side platform stations have platforms that accommodate only one train each, but each platform must have a full complement of vertical circulation elements and must accommodate both boarding and deboarding passengers. A triple platform station (also referred to as a "side-center-side" or "flow-through" station platform) has three separate platforms, each with a full complement of vertical circulation elements. In this case, the center platform serves as a boarding platform only and the two side platforms serve only as deboarding platforms. The automatic door sets for the deboarding platforms open several seconds before the door sets for the boarding platform. This establishes the proper queue movement and allows the fastest and most efficient boarding and deboarding of the train, although this station type is the most expensive and requires the most overall space.
- **Determine NFPA 130 compliance.** An excellent guide for life safety issues is the National Fire Protection Association's "NFPA 130—Standard for Fixed Guideway Transit and Passenger Rail Stations." Its content is well researched and is dedicated to specialized life safety issues. For example, the NFPA 130 test for emergency egress from a station is not a

typical/historical building code occupancy type analysis, but rather an analysis of time, distance, and pedestrian movement that most accurately reflects the real-world situation on the station platform. The reader is encouraged to review Section 8.4, Stations, for additional detailed discussion on this topic.

- **Develop and evaluate alternative station configurations and vertical circulation locations to determine the preferred station layout and size.** The guidelines given in this appendix and in Section 8.4, Stations, provide only an overview of basic APM station design parameters. An architect, in collaboration with an APM specialist, should fully explore different station configurations within the context of project-specific and site-specific factors in order to develop the most appropriate specific station design(s).

The reader is encouraged to note the decision diamond in Figure A-10 where the landside shuttle system of this example has now been planned to utilize center platforms approximately 120' long, with one elevator, one open stair (in addition to any required fire exits/stairs), and two pairs of escalators.

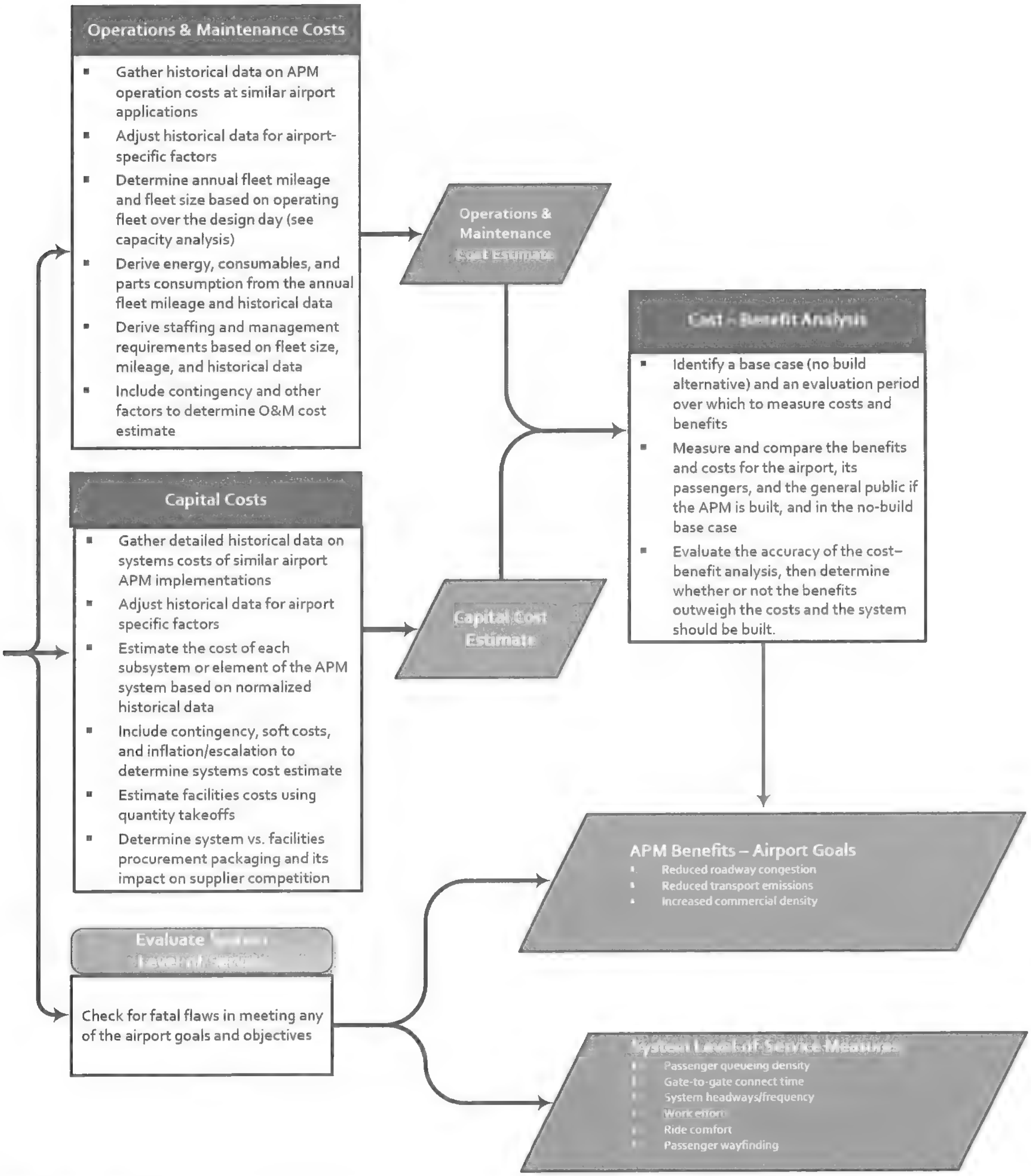
Cost Considerations

A variety of costs must be considered for the successful planning of an APM system. These costs include the initial capital costs required to implement the APM as well as the ongoing operations and maintenance costs of the system. In terms of APM planning, a cost–benefit analysis is recommended as a test of the overall viability of the APM system. This section focuses primarily on APM system costs and not the costs of the associated fixed facilities. This is because the costs associated with the APM system's fixed facilities can be estimated by a professional estimating firm. The APM system costs, on the other hand, vary widely within the APM industry because each different APM supplier uses a different and proprietary technology. Costs for different projects by the same supplier may also vary significantly because of different scales of economy involving fleet size, capacity requirements, level of bid competition, and so forth. Thus, estimating and comparing the cost of a proposed APM system against standard industry costs is difficult because repeatable and consistent costs within the industry are quite elusive.

The following discussion amplifies the cost considerations listed in the process blocks of Figure A-11 and offers relevant points to be considered in preparing system cost estimates.

Capital Costs

- **Gather detailed historical data on systems costs of similar airport APM implementations.** A key consideration is to ensure, to the greatest degree possible, the similar nature of the APM systems for which the capital cost data is being gathered. Since no two APM systems are identical, it is best to select a set of systems as similar to each other as possible and then adjust the capital costs according to the known differences from the system being compared.
- **Adjust historical data for airport-specific factors.** These factors can include the likelihood of union or open-shop labor and the associated local labor rates by category for appropriate building or highway labor categories. Other airport-specific and location-specific factors include local and national material costs and/or availability, local inflation and unemployment rates, and specific bonding requirements and the associated costs of procuring such bonds.
- **Estimate the cost of each subsystem or element of the APM system based on normalized historical data.** Breaking the estimated costs down by system and major subsystem facilitates the comparison, possible negotiation, and reconciliation of estimated costs with the proposed actual costs. Within the APM industry, there are fairly standardized breakdowns for both system estimates and the supplier's proposed costs. Although the total scope of these breakdowns is beyond the scope of this guidebook, the following are some major, industry-accepted breakdown categories: guideway facilities; station facilities; maintenance and storage facility; power distribution facilities; command, control, and communication facilities; fixed facility verification and acceptance; infrastructure and sitework; equipment rooms and UPS spaces; guideway equipment; station equipment; maintenance and storage facility equipment; power distribution system equipment; command, control, and communications equipment; vehicles; operating system verification and acceptance; and project management and administration.
- **Include contingency, soft costs, and inflation/escalation to determine systems cost estimate.** The total capital cost estimate will include factors such as contingency, escalation, and overhead and profit, in addition to soft costs that are associated with the design and construction management of the APM system. These factors are best determined and applied on a local and project-specific basis. Whether such factors are applied "above the line" or "below the line" in terms of labor and material subtotals is also best determined by the typical practices of the specific location and project.
- **Estimate facilities costs using quantity takeoffs.** As discussed in the introduction to this section, the fixed facility costs may be assigned to a conventional cost estimating entity; estimating the cost of the APM fixed facilities does not require any specialized expertise once the facilities are designed. However, it is recommended that an entity with experience in the APM industry coordinate with the cost estimator to ensure that any APM-specific issues are adequately addressed.



Source: Lea+Elliott, Inc.

Figure A-11. APM cost–benefit planning process.

- **Determine system versus facilities procurement packaging and its impact on supplier competition.** Within the APM industry, there are a variety of ways APM systems and associated fixed facilities can be procured; various methods are discussed in Chapter 10. Many procurement options exist, and the best approach should be determined by a specific procurement plan agreed to by all appropriate parties in accordance with local, state, and national law. Such a procurement plan is most appropriately developed after the planning stage of the system and is thus beyond the scope of this guidebook. However, general assumptions regarding the procurement approach, particularly with regard to packaging different contracts, are appropriate to consider when estimating the cost of the APM because such packaging can affect supplier competition and price. For example, for a small APM system, small suppliers may not have experience in, or even be capable of, proposing on a full DBOM approach to system implementation. Such factors should be considered in how the total work is packaged in terms of stand-alone contracts or contracts requiring a combination of construction trades. In addition, such packaging should be considered in conjunction with local practice and project-specific issues such as M/W/DBE participation goals.

Operations and Maintenance Costs

- **Gather historical data on APM operations costs at similar airport applications.** A key consideration is to ensure, to the greatest degree possible, the similar nature of the APM systems for which the data is being gathered in terms of all operational and technical parameters. Since no two APM systems are identical, it is best to select a set of systems as similar to each other as possible and then adjust the O&M costs according to the known differences from the system being compared.
- **Adjust historical data for airport-specific factors.** These factors can include the likelihood of union or open-shop labor and the associated local labor rates by category. Other airport-specific factors include the party that is intended to perform the O&M services, both initially and in the future. Options could include the initial supplier, a possible third party provider by way of competitive bids, or the airport's own in-house staff.
- **Determine annual fleet mileage and fleet size based on operating fleet over the design day (see capacity analysis).** Factors considered in the capacity analysis must also be considered in determining the fleet mileage, which determines the wear and tear on the vehicle fleet, which in turn determines the frequencies of major and minor maintenance intervals.
- **Derive energy, consumables, and parts consumption from the annual fleet mileage and historical data.** Some additional options for the airport to consider are how and where particular O&M costs will be accommodated and budgeted for. For example, parts and consumables might be included in the annual budget for an airport's maintenance department, whereas the electrical costs for system operations might be included in the annual budget of an airport's utility department.
- **Derive staffing and management requirements based on fleet size, mileage, and historical data.** Staffing for the APM system will consist of several different categories, and staffing will vary in proportion to system size and complexity. There are typically three work shifts that provide 24 hour coverage of the system 365 days per year. "First Shift" typically refers to the shift most closely approximating 8 a.m. to 5 p.m. "Third Shift" typically refers to the overnight shift when the system is operating off-peak and wayside and other maintenance tasks are best accomplished. "Second Shift" typically encompasses the 8 hours between first and third shifts. Staff categories typically consist of administrative and management staff, operations staff, and maintenance staff. The administrative staff typically includes a site manager and secretary or other clerical positions. Administrative staff typically works first shift. Operations staff typically includes the central control operators as well as mechanics and mechanics' helpers. Operations staff must cover all three shifts. Maintenance staff typically includes electrical technicians, mechanical technicians, and their helpers. Maintenance staff typically focuses their work during the third shift although there is typically overlap between operations and maintenance staff members and the shifts that they work.
- **Include contingency and other factors to determine the O&M cost estimate.** The total O&M cost estimate will include factors such as contingency, escalation, overhead, and profit, and these factors are best determined and applied on a local and project-specific basis. Whether such factors are applied "above the line" or "below the line" in terms of labor and material subtotals is also best determined by the typical practices of the specific location and project.

Cost–Benefit Analysis

At this point in the planning process, it is assumed that the proposed APM system's level of service has been checked for any fatal flaws in meeting the airport's goals and objectives and that complete O&M and capital cost estimates have been produced for the subject system. The next recommended step is to look at those costs in terms of a cost–benefit analysis. Detailed information regarding performance of a cost–benefit analysis for an airport APM is presented in Section 9.2.

- **Identify a base case (no-build alternative) and an evaluation period over which to measure costs and benefits.** The

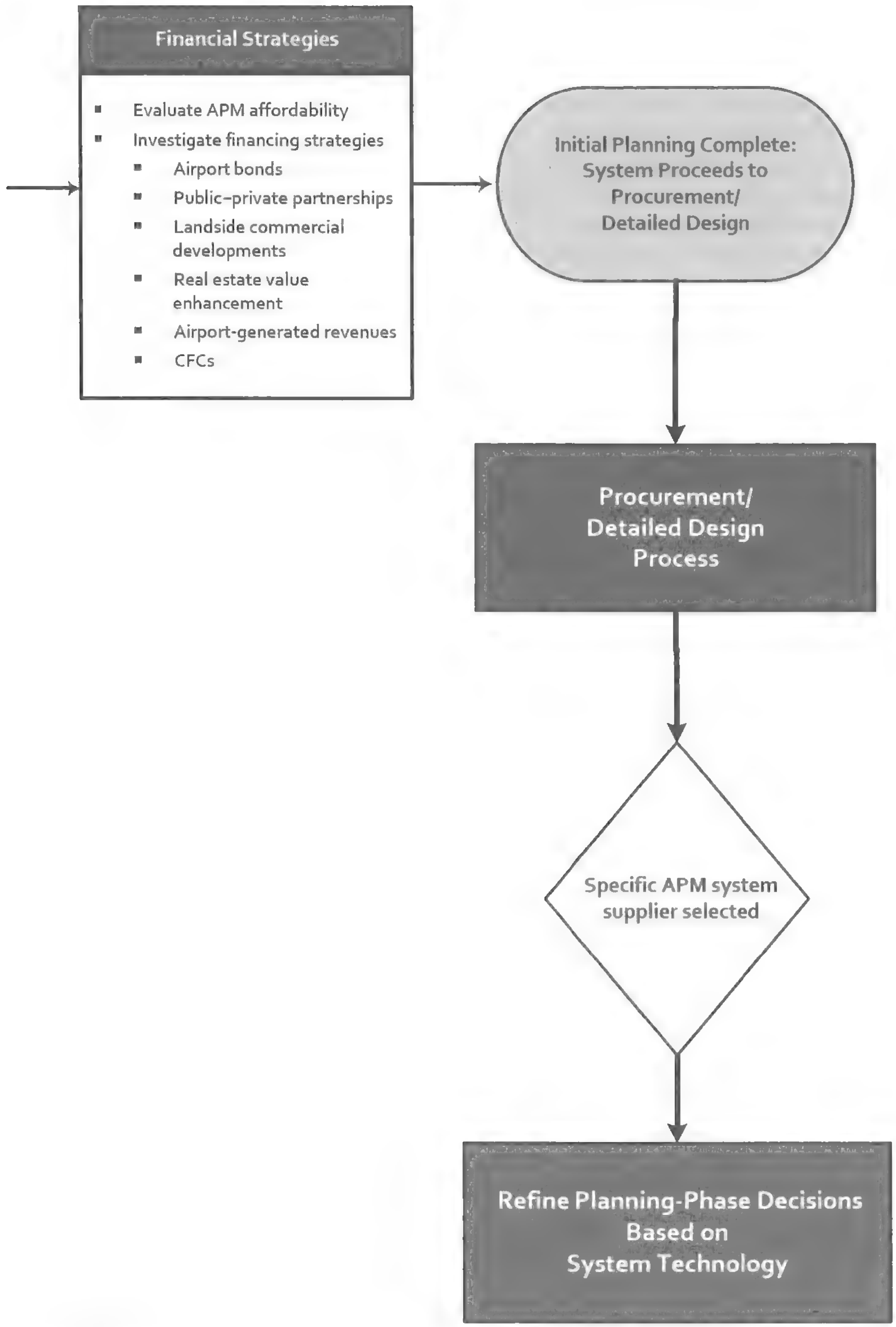
base case, no-build alternative must be evaluated over a period of time. The length of this time period should be commensurate with other projected time frames within which milestones affecting the airport will occur. For example, within what time frame is a particular percent increase in airport operations projected to occur? Within what time frame are a certain number of landside parking spaces projected to be required? Within what time frame is a new remote consolidated rental car facility or on-airport hotel projected to be built? The no-build base case should be evaluated within such time frames.

- **Measure and compare the costs and benefits for the airport, its passengers, and the general public if the APM is built and in the no-build base case.** Some benefits that can be compared are directly related to level-of-service issues affecting the airport's passengers and general public. Such issues may include travel time, walk distance, ease of wayfinding, work effort, and comfort and/or protection from the elements. Refer to Section 9.2 for more details. For landside APM systems, costs should be considered in terms of lost potential revenue as well as expenditures. For example, if the level of service provided by a landside APM would help motivate a four-star hotel chain to build a remote, yet on-airport, landside hotel, what is the lost revenue potential to the airport should the hotel and/or other transit-oriented development (TOD) not be built due to the lack of an APM?
- **Evaluate the accuracy of the cost–benefit analysis and then determine whether or not the benefits outweigh the costs and the system should be built.** The cost–benefit analysis will include some subjective criteria that are not as easily evaluated as objective data such as hard costs. Subjective data can be ranked, weighted, and empirically analyzed in a way that offers a fair, impartial, and accurate assessment and comparison. The parties appropriately charged with decision making should assure themselves that the cost–benefit analysis is accurate in terms of both subjective and objective data and base their ultimate build/no-build decision on this.

The reader is encouraged to note Figure A-11 where the landside system has been determined to have connectivity benefits that outweigh its cost.

Financial Strategies

- **Evaluate APM affordability.** Now that the APM system planning has been approved, its overall affordability must be assessed as part of the airport's projected capital program. This is illustrated graphically in the Figure A-12 flowchart. At this point, several options can be considered, depending upon the particular financial situation of the airport. If adequate funds exist, the entire system would likely move forward toward procurement and implementation. Another option would be to phase in the implementation of the system in order to extend cash flow requirements. Note that this approach, although not uncommon, results in cost deferment, not cost savings, and the final cost for full system implementation is invariably greater due to inflation factors.
- **Investigate financing strategies.** Different financing strategies are airport-specific and depend upon a variety of factors, including whether the airport is functionally a department of its host city or is controlled by an independent quasi-governmental body. This difference and others play a role in how the particular airport's rates, fees, and charges are assessed and managed. The following are examples of some of the more common funding avenues for landside APM systems although they may not apply to the particular airport at hand.
  - **Airport Bonds.** Such bonds may be joint revenue bonds where debt service is shared widely among all airport stakeholders. In addition, airports may issue special facility bonds where the debt service is assigned to a single entity, such as an airline, or a small pool of users. Special facility bonds are typically used to fund dedicated-use projects whereby the project's use is virtually exclusive to the bond guarantor.
  - **Public–private partnerships.** A public–private partnership (sometimes referred to as PPP or P3) is a contractual agreement between a public-sector agency and a private-sector business venture where the parties combine their skills and assets to build and operate a public-use facility. Each sector (public and private) also shares in the risks and rewards associated with the project. Although P3s have been used to provide public services, most involve physical facilities. Of these public-use facilities, civil and structural infrastructure (roadways, bridges) are most common, but transit projects are not unusual. The specifics of the contractual agreement between the parties are crafted in accordance with the particulars of the political and statutory environment, the project itself, and a host of other factors. Such agreements are complex and the option of P3 financing is best explored with an entity of proven experience in this field.
  - **Landside commercial developments.** If a main purpose of the landside APM is to serve landside commercial development, funding for the APM could be pursued as part of such development, or if the commercial development is by an entity totally independent from the airport, funding by that entity could be pursued. The percentage of the total funding by the entities separate from the airport would likely depend upon the proportional levels of service provided by the APM. If the APM links commercial development to a regional rail system (with an intermodal station at the airport's main terminal), then the



Source: Lea+Elliott, Inc.

Figure A-12. Final APM planning process.

rental revenue potential of the development may be increased due to the improved regional access, as well as through potential density/height increases to the development via zoning waivers tied to the transit access.

- **Airport-generated revenues.** Assuming such revenue is specifically self-generated by the airport, this funding typically has few use restrictions. Airports have multiple self-generated revenue streams, the largest of which come from landing fees, concession and other lease agreements, and parking fees. Other airport-generated revenue may be tied to the specific development opportunities of the particular airport. For example, DFW International Airport was able to generate a substantial revenue stream by negotiating on-airport drilling rights with natural gas drilling companies.
- **Customer facility charges.** An example of a CFC is where the airport, in accordance with a joint use agreement with its airlines, rental car companies and/or other tenants, assesses dedicated fees to fund particular projects or facilities. In recent years, this example has been commonly applied to fund both the construction and operation of consolidated rental car facilities. Typically, the customer actually sees the CFC listed on the receipt for the car rental. If the landside APM serves the rental car facility, its costs (total or partial) could be included in the CFC.

Note that in these examples, the charge is made via the rental car company and not directly by the airport (as parking fees are, for example), and the fee is not exclusively for the APM system. A precedent regarding airport APMs is that their ridership is free of charge, primarily because riding an APM in an airport environment is typically perceived as being necessary or required to reach a certain destination. Although this may be less true for a landside system as opposed to an airside system, and although virtually no other form of public transit is free, the public's perceived entitlement to riding free on a landside APM will likely remain. CFCs have not typically been assessed directly by airport authorities exclusively for funding APM systems, but nothing precludes this other than lack of precedent and the public relations hurdle of overcoming the passenger's perceived entitlement to riding free.

The reader is encouraged to note the final decision diamond and process boxes in Figure A-12 where the planning for the theoretical landside system has been completed with the system moving into the procurement and detailed design phases. Of particular note is the fact that once a specific APM technology is selected, it is often necessary to revisit and refine some of the planning phase decisions. At the end of this appendix, a number of underground, airside APM alignments are provided as examples of the type of system that has emerged from the APM planning process described above. For specific details on these existing airside APMs, please see Appendix B.

Resulting Systems

Table A-1 summarizes the relevant characteristics of the airside and landside APM systems resulting from the theoretical planning process for Examples 1 and 2. Because of the proprietary nature of APM systems and project-specific requirements for each APM system, the table is not meant to describe the precise design characteristics of the subject systems. Such specifics are typically defined by the APM supplier during the design-build process. The purposes of the planning process for an APM are to confirm the viability of the APM system and if viable, to identify characteristics and costs of the APM system to a degree that will allow the airport to:

1. Develop the procurement documents for use in procuring the APM and,
2. Confirm and provide proper and adequate funding for the APM.

Further explanation of points (1) and (2) are as follows:

The planning process results in parameters for the procurement documents, which include system performance specifications. Performance specifications are commonly used in the APM industry, as opposed to a standard Construction Specification Institute specification, which is typically used for conventional construction projects. In simplest terms, an APM performance specification tells the APM supplier what to design but not exactly how to design it. For example, Figure A-4 shows that the planning process resulted in three-car trains using 40-foot vehicles for the pinched-loop airside system. This may be accurate for most APM suppliers proposing on the theoretical system, but a particular supplier may propose four-car trains using 30-foot vehicles if that were the supplier's proprietary vehicle. Assuming all other performance characteristics and specifications are met, this alternate train configuration would be acceptable.

The planning process results in parameters accurate enough for developing the planning-level estimates of the APM system's initial capital costs as well as an estimate of the ongoing O&M costs. Although, as in the foregoing example of three-car versus four-car trains, it is not possible to know with complete certainty if all the planning parameters will be met exactly as anticipated in the final design of the APM system, such potential differences are typically discounted for purposes of estimating. This is based on experience that indicates that the aspect of competition between suppliers is an overriding factor in their proposal pricing, compared to such differences between the proprietary aspects of their systems.

Table A-1. Characteristics of relevant APM systems.

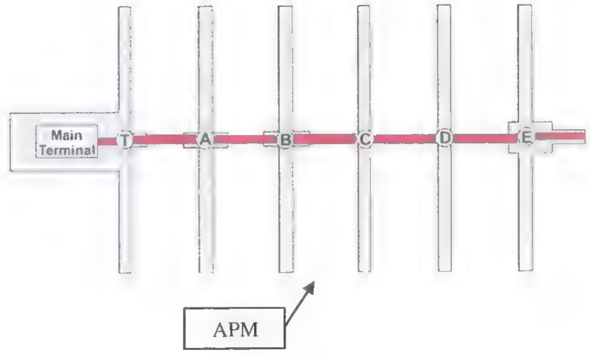
	Example 1	Example 2
	Airside – Service to three terminal stations, one at each of three freestanding terminals – HUB airport	Landside – Service to one terminal station, an intermodal facility and/or parking structure.
Guideway Length (dual-lane miles)	1.5	0.5
Alignment	Underground, pinched-loop	Elevated, dual-lane shuttle
System Capacity	6,000	2,500
No. of Vehicles (Total Fleet)	24	6
Capacity/Car[1]	75	50
Cars/Train[1]	3	3
Area/Passenger	3.3 ft^2	5 ft^2
No. of Trains	8	2
Peak Hour Headway	2.3 minutes	3.6 minutes
Propulsion	Power rail 600 VAC	Cable 480 VAC cable drive motors
No. of Power Substations	3 to 4	1
Maintenance Facility	Offline	Online – under an end station
Ready/Receiving/Test Track	0.2 miles of ready/receiving track	Guideway serves as test track
Central Control Facility location & staff	CCF located within MSF – three CCOs on duty	CCF located within airport operations center – one CCO on duty
Number of Stations	3	2 to 3
Station Platform Type	Side-center-side	Center
Vertical Circulation	One elevator, one stair, and two single-direction escalators for each of the three platforms at each station	One elevator, one stair, and two pairs of escalators per station

[1]Single APM car or vehicle is the typical 40-foot-long car offered by many suppliers.

Source: Lea+Elliott, Inc.

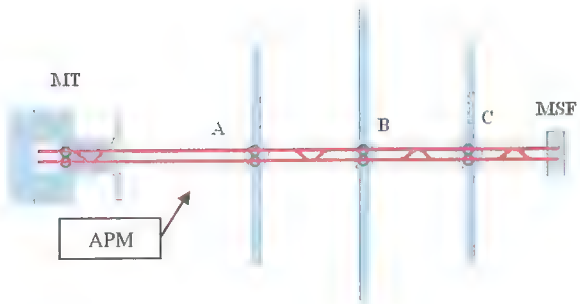
Atlanta – Airside

- Seven stations, 1.1 miles of guideway
- Underground, pinched loop
- Four vehicles per train, with 1.8-minute headway
- Fleet size of 49 vehicles with 10,000 pphpd



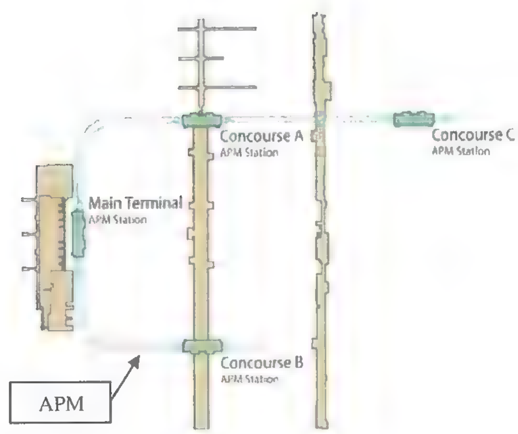
Denver – Airside

- Four stations, 1.2 miles of guideway
- Underground, pinched loop
- Four vehicles per train, with 2.0-minute headway
- Fleet size of 31 vehicles with 8,300 pphpd



Washington Dulles – Airside

- Four stations, 1.4 miles of guideway
- Underground, pinched loop
- Three vehicles per train, with 1.9-minute headway
- Fleet size of 29 vehicles with 7,105 pphpd



Atlanta – Landside

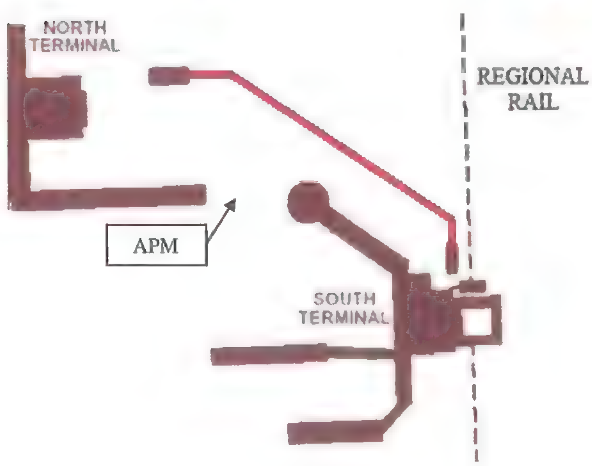
- Three stations, 1.4 miles of guideway
- Elevated, pinched loop
- Two vehicles per train, with 2.0-minute headway
- Fleet size of 12 vehicles with 2,700 pphpd

Birmingham (U.K.) – Landside

- Two stations, 0.4 miles of guideway
- Elevated, shuttle
- Two vehicles per train, with 2.0-minute headway
- Fleet size of four vehicles with 1,608 pph

London Gatwick – Landside

- Two stations, 0.7 miles of guideway
- Elevated, shuttle
- Three vehicles per train, with 2.6-minute headway
- Fleet size of six vehicles with 4,200 pphpd



APPENDIX B

Inventory of Airport APM Systems

This chapter provides an inventory of existing airport APMs. The inventory of APMs at airports changes rapidly as new airports implement their first APM and other airports expand their existing system or add a second or third APM to their facility.

The inventory describes the existing airport APMs in their current state. The data included in this report were collected through February 2010. Many systems have expanded significantly since their opening date. Expansions have taken the form of longer trains, more trains, longer alignments, changes to operating configuration, and combinations thereof. Given the dynamic nature of existing airport APMs and new systems expected to open in the near future, this inventory will quickly become out of date.

Detailed information is provided for the 44 current airport APMs. Data was collected from many sources and may not be fully comparable in all cases. Information is provided for each airport APM application for a wide range of institutional and operation environments. The definition for each of these areas is provided below.

Inventory Definitions

City/country—The city and country in which the APM system is located.

Airport/airport code—The name of the airport where the APM system is located and the three-letter IATA airport code.

System name—The name of the APM system.

Role—The role that the APM system plays at the airport. Examples include the type of passenger (airside, landside, international, etc.) conveyed by the system or major activity centers that the system connects such as parking garages, consolidated rental car facilities, regional rail, airport terminal buildings, and satellite terminal buildings.

Benefit—The benefit realized by the airport as a result of having the APM system.

Impact on MAP—The impact that the APM system has on the airport's total number of passengers as measured by MAP. An airport APM system can have a positive impact on the number of transfer passengers if not the number of O&D passengers. Alternately, an airport APM system may have no impact on transfer and/or O&D passengers. The impact of the APM system on transfer and O&D passengers is related to factors such as whether it is located airside or landside and if it connects to other terminals, remote parking, regional rail, and so on.

Impact on trip time—The impact that the APM system has on passenger trip times. An airport APM system can have a positive impact on a passenger's trip time by shortening its duration. An APM system can have a positive impact on transfer passenger trip times and/or O&D passenger trip times. For some passengers, an airport APM system may have no impact on transfer and/or O&D passenger trip times. The impact of the APM system on transfer and O&D passenger trip times is related to factors such as whether it is located airside or landside and if it connects to other terminals, remote parking, regional rail, and so on.

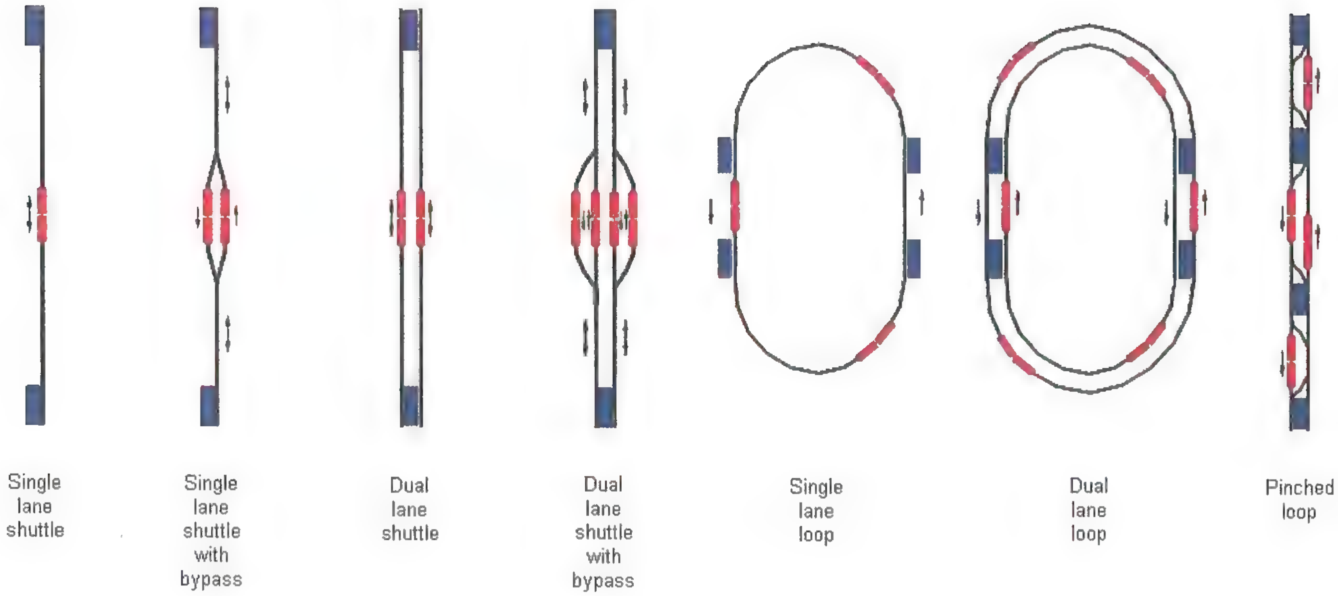
Operating entity—The name of the organization that operates the APM. It is typical for airport owners to contract out the O&M of the system to another organization, often the APM system supplier.

In service year—The year that the APM system started operation.

Supplier—The manufacturer of the APM operating system.

Model—The model name of the APM vehicles.

System operating configuration—The configuration of the guideway and how the vehicles navigate it. Examples include single-lane shuttle, single-lane shuttle with bypass,



dual-lane shuttle, dual-lane shuttle with bypass, single-lane loop, dual-lane loop, and pinched loop. See Section 4.2 for a detailed description of the operating configuration alternatives. This also includes elevation type, which would fall under one of the three categories of elevated, at grade, or underground.

Guideway length—The length of the guideway, typically measured in units of dual-lane guideway miles. For example, if a dual-lane shuttle as in the exhibit above is 1.5 miles from end to end, this could be represented as 1.5 miles of dual-lane guideway, not 3.0 miles of single-lane guideway. The guideway lengths are only the operating lengths and do not include portions that extend to maintenance facilities.

Vehicles per train—The number of vehicles coupled together to form a train, also known as the consist. This can vary at an application over time (even within a day) but is intended to represent the train size most often used by the airport. A car is the smallest individual unit but is not able to operate on its own. A vehicle is the smallest individual unit that can operate on its own. A train is composed of cars and/or vehicles.

Fleet size—The total number of vehicles in the APM system, including spares.

Propulsion—The method used by the system to move the vehicles on the guideway. All of the systems currently employed at airports are electrically powered.

Control system—The system and/or software used by the APM for automatic, driverless operation.

Peak hour capacity—The maximum number of passengers that the APM system can transport in one direction in the busiest hour of service. This number (pphpd) is a function of the available vehicle floor area, the passenger loading density, and the APM train frequency or headway.

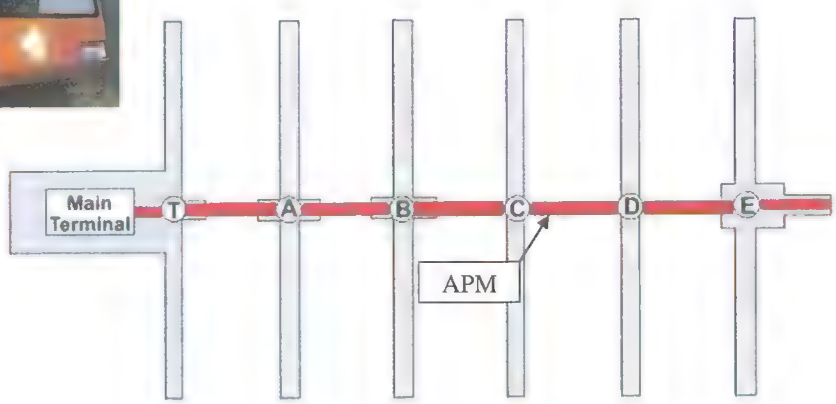
Peak hour headway—The time between successive train arrivals (same guideway) at a station during peak hour operations.

Comments—Additional comments regarding past replacements, current status, or future extension of the APM system

A system photo and alignment graphic is provided for each APM. These photos and graphical images were obtained from a range of sources including supplier and airport websites, APM conference papers and brochures, Wikipedia, and previous Lea+Elliott projects. References for all photos and alignment graphics are provided at the end of this appendix.

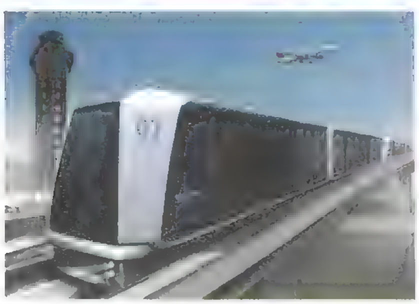
Atlanta Airside

City/Country:	Atlanta/USA
Airport/Airport Code:	Hartsfield–Jackson Atlanta International Airport/ATL
System Name:	Concourse People Mover
Role:	Airside conveyance, between main terminal and satellite concourses
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	1980
Supplier:	Bombardier
Model:	CX-100
System Operating Configuration:	Pinched loop, underground
Guideway Length:	1.0 mile (1.6 km) dual-lane guideway
Vehicles Per Train:	Four
Fleet Size:	Twelve four-vehicle trains with one extra vehicle
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	Automated, relay-based fixed block
Peak Hour Capacity:	10,000 pphpd
Peak Hour Headway:	1.8 minutes
Comments:	Since opening in 1980, the Atlanta system has seen fleet expansions from 12 to 49 vehicles, alignment extensions, MSF relocation and expansion, and two generations of replacement vehicles. An additional project is currently under implementation to extend the east Concourse F and is expected to be operating by 2012.



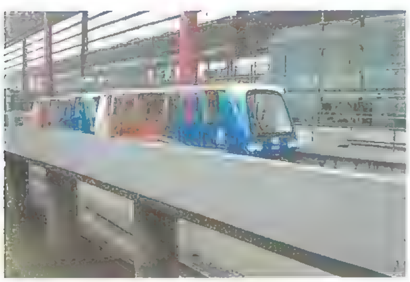
Atlanta Landside

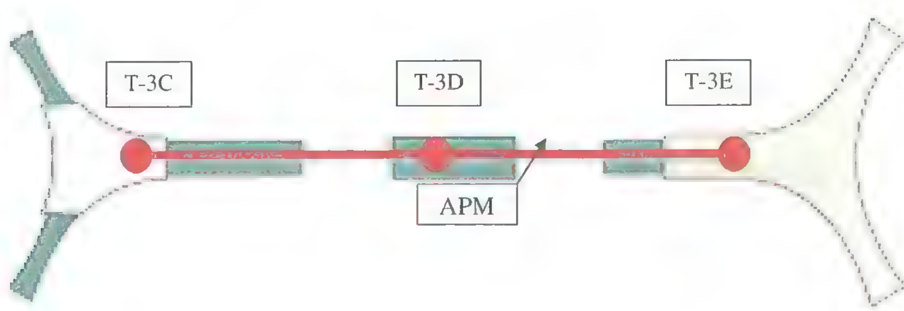
City/Country:	Atlanta/USA
Airport/Airport Code:	Hartsfield–Jackson Atlanta International Airport/ATL
System Name:	Consolidated Rental Agency Complex (CONRAC)
Role:	Landside conveyance between rental car facility and passenger terminal
Benefit:	Reduces airport roadway congestion, connects airport terminals to adjacent commercial property
Impact on MAP:	Positive impact on O&D MAP
Impact on Trip Time:	Positive impact on O&D trip time
Operating Entity:	Mitsubishi
In Service Year:	2009
Supplier:	Mitsubishi Heavy Industries
Model:	Crystal Mover
System Operating Configuration:	Pinched loop, elevated
Guideway Length:	1.4 mile (2.3 km) dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	Six two-vehicle trains
Propulsion:	VVVF inverter vector control
Control System:	Automated, microprocessor-based fixed block
Peak Hour Capacity:	2,700 pphpd
Peak Hour Headway:	2.0 minutes



Beijing Airside

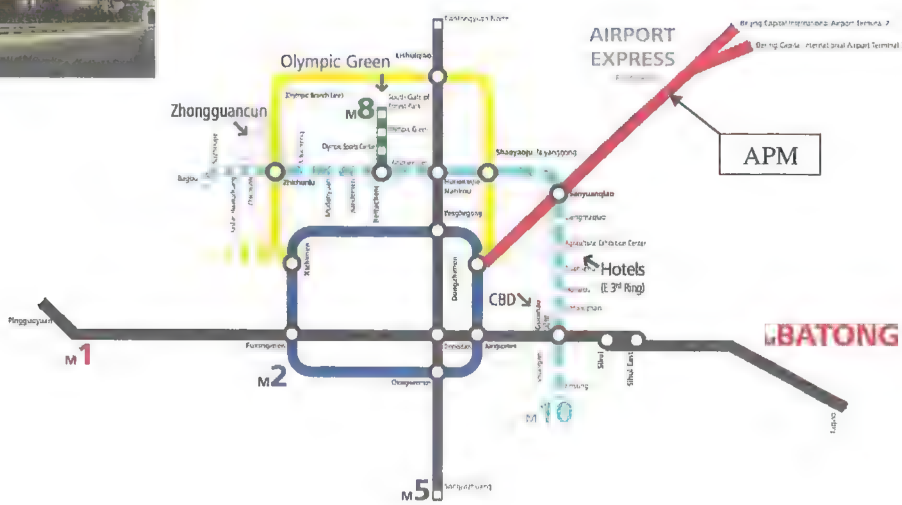
City/Country:	Beijing/China
Airport/Airport Code:	Beijing Capital International Airport/PEK
System Name:	Automated People Mover System
Role:	Airside conveyance, connects Terminals 3A, 3B, and 3C
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time
Operating Entity:	Bombardier Transportation
In Service Year:	2008
Supplier:	Bombardier
Model:	CX-100
System Operating Configuration:	Pinched loop, at grade
Guideway Length:	1.2 miles (2.0 km) dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	Five two-vehicle trains with one extra vehicle
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	CITYFLO 550 microprocessor-based fixed block
Peak Hour Capacity:	4,100 pphpd
Peak Hour Headway:	5.0 minutes





Beijing Landside

City/Country:	Beijing/China
Airport/Airport Code:	Beijing Capital International Airport/PEK
System Name:	Airport Express Train
Role:	Landside conveyance, connects Beijing's urban center with the international airport's Terminals 2 and 3
Benefit:	
Impact on MAP:	Positive impact on O&D MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Beijing Mass Transit Railway Operation Corporation
In Service Year:	2008
Supplier:	Bombardier
Model:	MK II
System Operating Configuration:	Pinched loop, elevated
Guideway Length:	17.5 miles (28.1 km) dual-lane guideway
Vehicles Per Train:	Four
Fleet Size:	Ten four-vehicle trains
Propulsion:	750 Vdc; third rail, linear induction motor
Control System:	Automated, communication-based train-control system
Peak Hour Capacity:	3,780 pphpd
Peak Hour Headway:	4.0 minutes

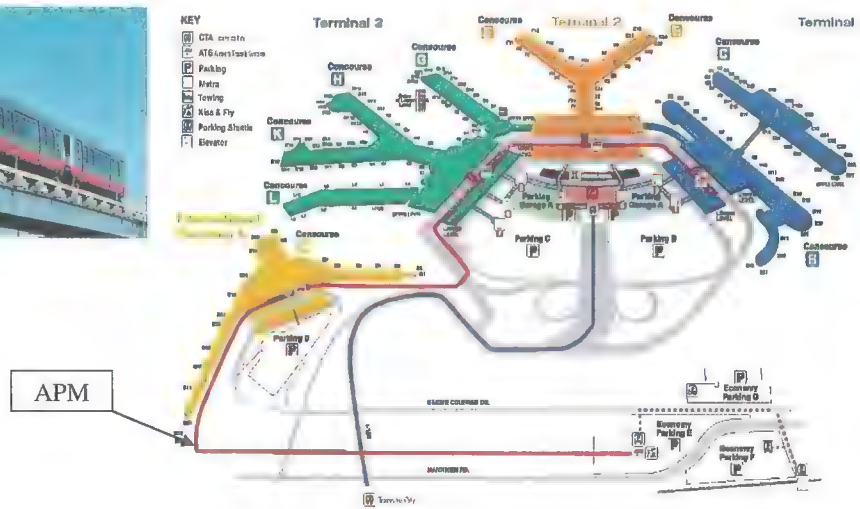


Birmingham

City/Country:	Birmingham/United Kingdom
Airport/Airport Code:	Birmingham International Airport/BHX
System Name:	Air-Rail Link
Role:	Landside conveyance, connect airport terminal to nearby regional rail and exhibition center
Benefit:	Reduces O&D parking demand and airport roadway congestion
Impact on MAP:	No impact on airport MAP
Impact on Trip Time:	No impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	DCC Doppelmayr
In Service Year:	2003
Supplier:	DCC Doppelmayr
Model:	Cable Liner Shuttle
System Operating Configuration:	Dual-lane shuttle, elevated
Guideway Length:	0.4 miles (0.6 km) dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	Two two-vehicle trains
Propulsion:	Cable-propelled, 415 Volts, 50 Hertz
Control System:	Fully automated, based on a fail-safe programmable logic controller (PLC) technology
Peak Hour Capacity:	1,608 pphpd
Peak Hour Headway:	2.0 minutes
Comments:	Replaced a previous low-speed maglev system. The original guideway columns and beams were kept; the separate DCC guideway structure is supported on the existing columns.

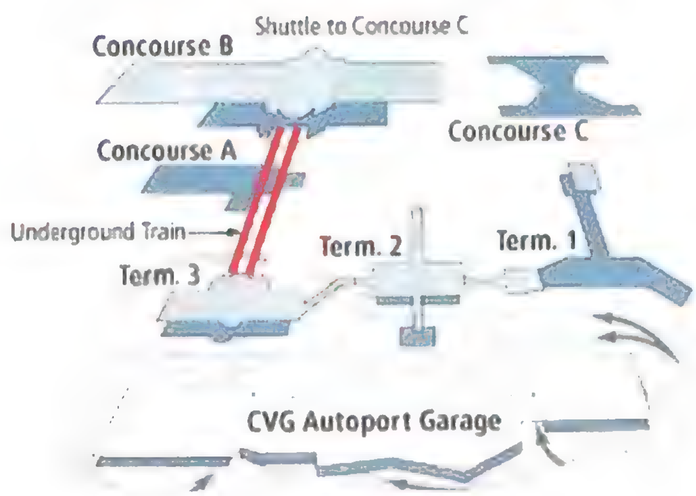
Chicago

City/Country:	Chicago/USA
Airport/Airport Code:	Chicago O'Hare International Airport/ORD
System Name:	Airport Transit System (ATS)
Role:	Landside conveyance, connects three domestic terminals, international terminal, long-term parking. Access to CTA Station via walking and to PACE stop via shuttle bus
Benefit:	Reduces O&D parking demand and airport roadway congestion
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	O'Hare Airport Transit System (OATS)
In Service Year:	1993
Supplier:	Siemens
Model:	VAL 256
System Operating Configuration:	Dual lane, pinched loop, primarily elevated
Guideway Length:	2.7 miles (4.3 km) dual-lane guideway
Vehicles Per Train:	One to three
Fleet Size:	15 vehicles
Propulsion:	Rotary, electric, 750 Vdc, traction motors
Control System:	Automated, fixed-block
Peak Hour Capacity:	2,400 pphpd
Peak Hour Headway:	3.0 minutes



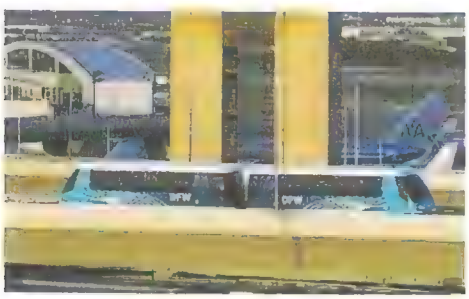
Cincinnati

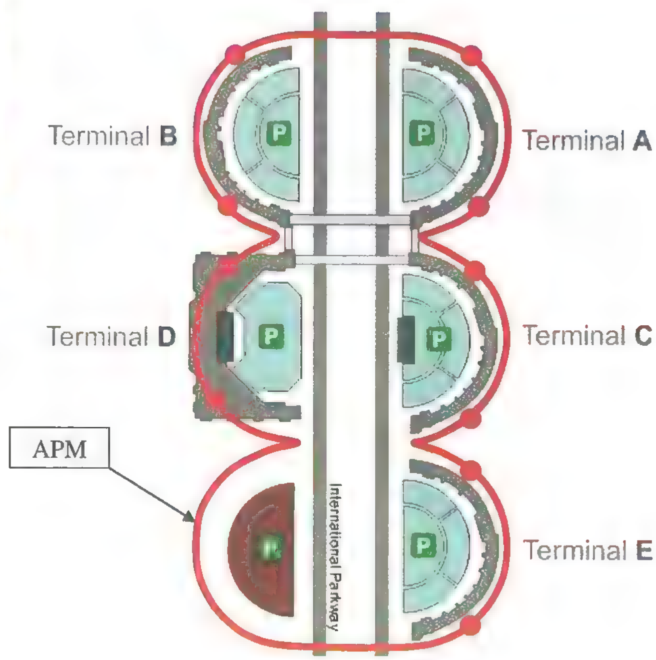
City/Country:	Cincinnati/USA
Airport/Airport Code:	Cincinnati/Northern Kentucky International Airport/CVG
System Name:	Concourse Train
Role:	Airside conveyance, connects Terminal 3 to Satellite Concourses A & B
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Otis
In Service Year:	1994
Supplier:	Poma-Otis
Model:	Hovair
System Operating Configuration:	Dual-lane shuttle, underground
Guideway Length:	0.2 miles (0.4 km) dual-lane guideway
Vehicles Per Train:	Three
Fleet Size:	Two three-vehicle trains
Propulsion:	Cable-propelled, DC motors
Control System:	Fully automated, based on a fail-safe PLC technology
Peak Hour Capacity:	5,700 pphpd
Peak Hour Headway:	2.2 minutes



Dallas/Fort Worth

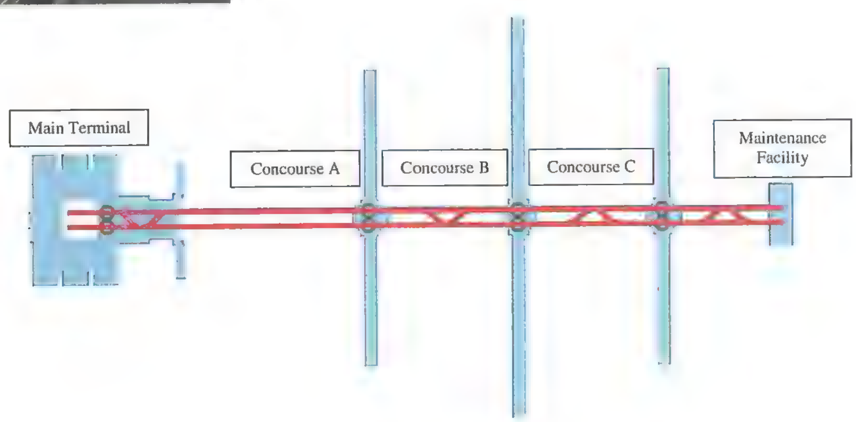
City/Country:	Dallas/Fort Worth/USA
Airport/Airport Code:	Dallas/Fort Worth International Airport/DFW
System Name:	Skylink
Role:	Airside conveyance, moves transfer passengers between terminals
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, no impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	2005
Supplier:	Bombardier
Model:	Innovia
System Operating Configuration:	Bi-directional, dual-lane loop, elevated
Guideway Length:	4.9 miles (7.9 km) dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	32 two-vehicle trains (64 vehicles)
Propulsion:	AC traction motors, 750 Vdc supply, guideway-mounted power rail
Control System:	CITYFLO 650 moving block automated train control
Peak Hour Capacity:	5,000 pphpd
Peak Hour Headway:	2.0 minutes
Comment:	Replaced the original Airtrans APM system.





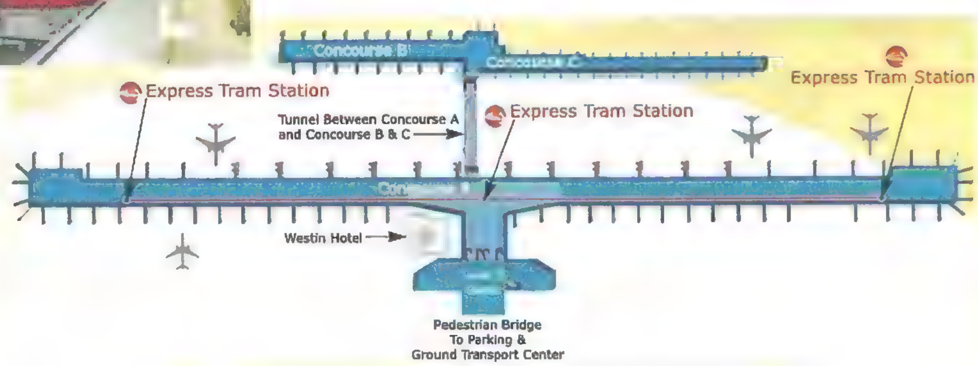
Denver

City/Country:	Denver/USA
Airport/Airport Code:	Denver International Airport/DEN
System Name:	Automated Guideway Transit System (AGTS)
Role:	Airside conveyance, main terminal to/from satellite concourses A, B, & C
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	1995
Supplier:	Bombardier
Model:	CX-100
System Operating Configuration:	Pinched loop, underground
Guideway Length:	1.2 miles (1.9 km) dual-lane guideway
Vehicles Per Train:	Four
Fleet Size:	Seven four-vehicle trains with three extra vehicles
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	Automated, relay-based fixed block
Peak Hour Capacity:	8,300 pphpd
Peak Hour Headway:	2.0 minutes
Comments:	Since the AGTS system opened in 1995 it has expanded from 16 vehicles to the current 31 vehicles.



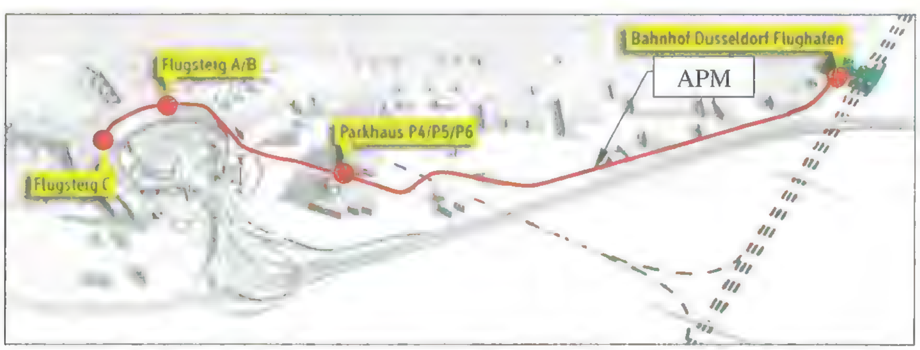
Detroit

City/Country:	Detroit/USA
Airport/Airport Code:	Detroit Metropolitan Wayne County Airport/DTW
System Name:	Express Tram
Role:	Airside conveyance, moves passengers within McNamara terminal
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Otis
In Service Year:	2002
Supplier:	Poma-Otis
Model:	8-door, 54' vehicles, Hovair ®,
System Operating Configuration:	Single-lane shuttle with bypass, elevated
Guideway Length:	0.7 miles (1.1 km) dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	Two two-vehicle trains
Propulsion:	Cable-propelled, DC motors
Control System:	Fully automated, based on a fail-safe PLC technology
Peak Hour Capacity:	4,000 pphpd
Peak Hour Headway:	3.2 minutes



Düsseldorf

City/Country:	Düsseldorf/Germany
Airport/Airport Code:	Düsseldorf International Airport/DUS
System Name:	Skytrain (Suspended Monorail)
Role:	Landside conveyance, connects the main terminal to the car park and rail station
Benefit:	Reduces O&D parking demand and airport roadway congestion
Impact on MAP:	No impact on airport MAP
Impact on Trip Time:	No impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Flughafen Düsseldorf GmbH
In Service Year:	2002
Supplier:	Siemens
Model:	H-Bahn
System Operating Configuration:	Pinched loop, elevated
Guideway Length:	1.6 miles (2.5 km), dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	Six two-vehicle trains
Propulsion:	Conventional rotary motors
Control System:	Automated, moving block system
Peak Hour Capacity:	2,000 pphpd
Peak Hour Headway:	5.0 minutes

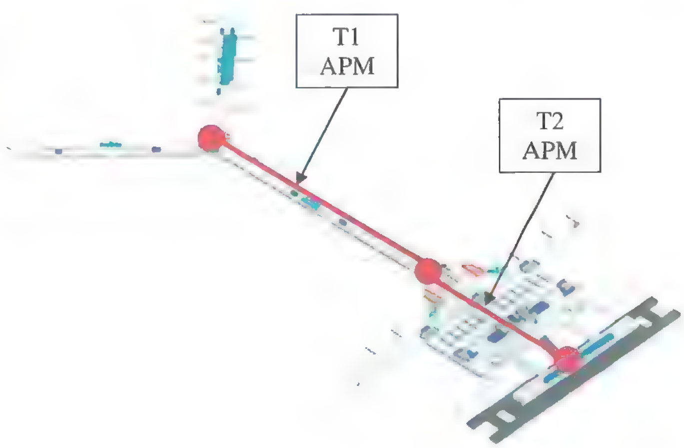


Frankfurt

City/Country:	Frankfurt/Germany
Airport/Airport Code:	Frankfurt Airport/FRA
System Name:	Sky Line
Role:	Airside conveyance, transports passengers between Concourses A-D and the Main Terminal
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	1994
Supplier:	Bombardier
Model:	CX-100
System Operating Configuration:	Pinched loop, elevated
Guideway Length:	1.0 miles (1.6 km) dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	Nine two-vehicle trains
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	CITYFLO 550 microprocessor-based fixed block
Peak Hour Capacity:	4,500 pphpd
Peak Hour Headway:	2.0 – 3.0 minutes

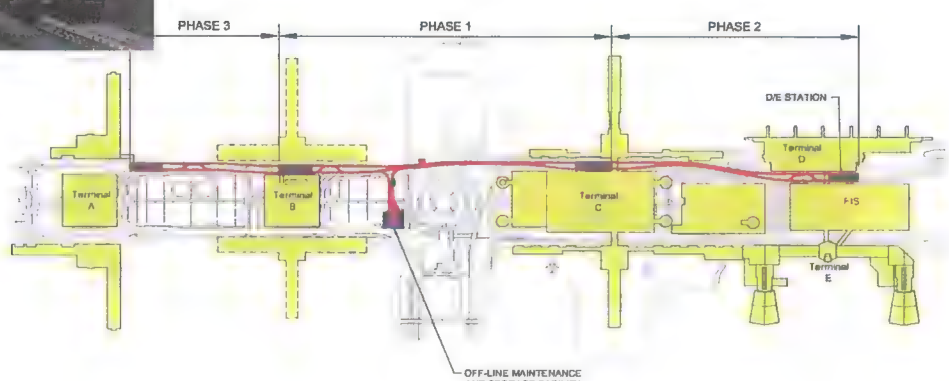
Hong Kong

City/Country:	Hong Kong/China
Airport/Airport Code:	Hong Kong International Airport/HKG
System Name:	The shuttle
Role:	Airside conveyance, transports passengers whose flights are located at the West Hall, Southwest and Northwest concourses
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Mass Transit Rail (MTR)
In Service Year:	T1 (PTB) line – 1998, T2 (SkyPlaza) line – 2008
Supplier:	Sumitomo/Mitsubishi (initial T1 system) and IHI/Niigata (T2 line)
Model:	T1 – Crystal Mover, T2 – Japanese standard technology
System Operating Configuration:	T1 – Pinched loop, underground, T2 – Dual-lane shuttle, underground
Guideway Length:	T1 – 0.4 miles (0.6 km) dual-lane guideway, T2 – 0.4 miles (0.6 km) dual-lane guideway
Vehicles Per Train:	Four and two
Fleet Size:	28 vehicles; five four-vehicle trains and four two-vehicle trains
Propulsion:	VVVF inverter vector control
Control System:	Automated, fixed block
Peak Hour Capacity:	T1 – 6,000 pphpd, T2 – 3000 pphpd
Peak Hour Headway:	T1 – 2.0 minutes, T2 – 4.5 minutes
Comments:	A new extension of the T2 (SkyPlaza) line called "SkyPier" is now under construction and due to be completed in 2009.



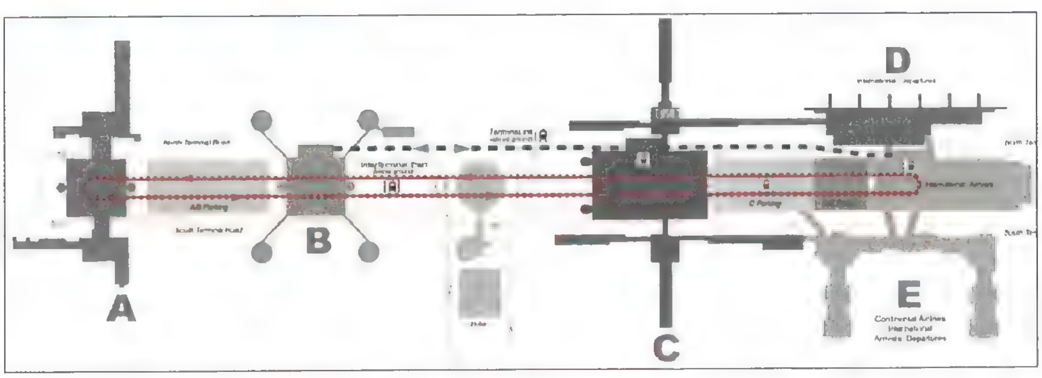
Houston Airside

City/Country:	Houston/USA
Airport/Airport Code:	George Bush Intercontinental Airport/IAH
System Name:	TerminaLink
Role:	Airside conveyance, transports passengers between terminals and FIS
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Johnson Controls, Inc. (SDI)
In Service Year:	1999 Phase 1, 2005 Phase 2, 2010 Phase 3
Supplier:	Bombardier
Model:	CX-100
System Operating Configuration:	Pinched loop, elevated
Guideway Length:	1.0 miles (1.6 km) dual-lane guideway (Phase 3)
Vehicles Per Train:	Two
Fleet Size:	Eight two-vehicle trains (Phase 3), Six two-vehicle trains in operation (Phase 3)
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	CITYFLO 550 microprocessor-based fixed block
Peak Hour Capacity:	4800 pphpd Phase 2, 5000 pphpd Phase 3
Peak Hour Headway:	1.85 minutes
Comments:	The system is being built in three phases, as shown on the system map below. The third phase is currently under construction and is expected to open in 2010.



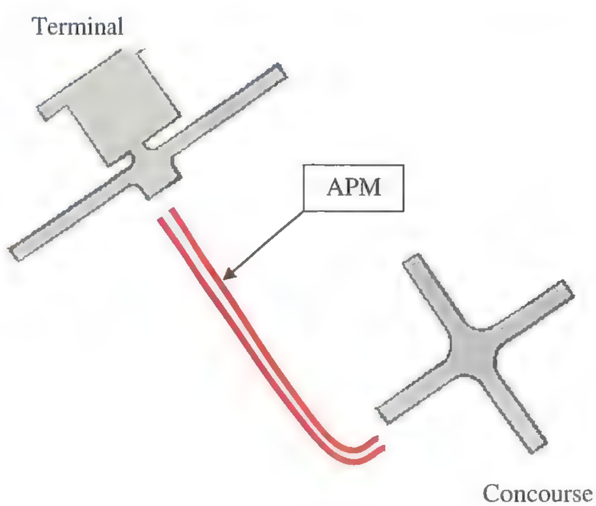
Houston Landside

City/Country:	Houston/USA
Airport/Airport Code:	George Bush Intercontinental Airport/IAH
System Name:	Inter-Terminal Train
Role:	Landside conveyance, transports passengers between terminals, parking, and hotel
Benefit:	Reduces O&D parking demand and airport roadway congestion
Impact on MAP:	No impact on airport MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Johnson Controls, Inc. (JCI)
In Service Year:	1981
Supplier:	Bombardier (formerly TGI)
Model:	WEDway People Mover
System Operating Configuration:	Loop, underground
Guideway Length:	2.0 miles (3.2 km) single-lane guideway
Vehicles Per Train:	Three
Fleet Size:	Eight three-vehicle trains, Six two-vehicle trains
Propulsion:	LIMs embedded in the track
Control System:	PLC fixed block control of wayside linear induction motors (passive vehicles)
Peak Hour Capacity:	720 pphpd
Peak Hour Headway:	3.0 minutes



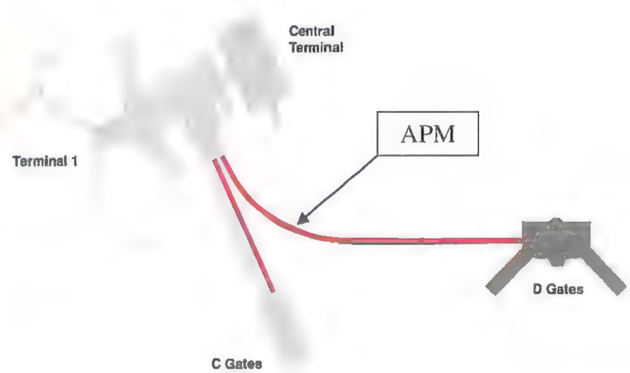
Kuala Lumpur

City/Country:	Selangor Darul Ehsan/Malaysia
Airport/Airport Code:	Kuala Lumpur International Airport/KUL
System Name:	Aerotrain
Role:	Airside conveyance, transports passengers from main terminal to satellite concourse
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	1998
Supplier:	Bombardier
Model:	CX-100
System Operating Configuration:	Dual-lane shuttle, elevated and underground
Guideway Length:	0.8 miles (1.3 km) dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	Two two-vehicle trains
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	Fully automated, solid state
Peak Hour Capacity:	3,000 pphpd
Peak Hour Headway:	3.0 minutes
Comments:	The system is currently being expanded to service a new terminal and is expected to be operating by 2011.



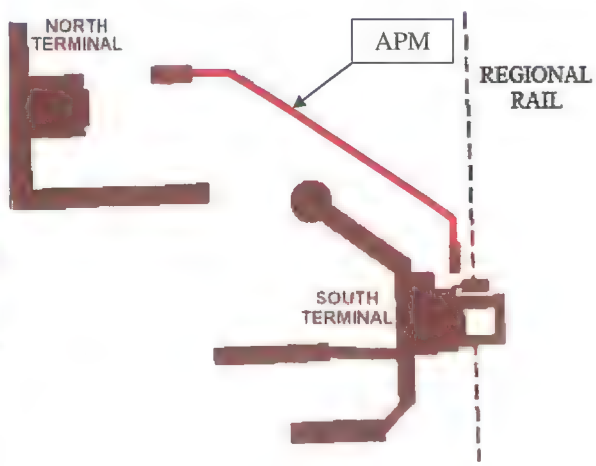
Las Vegas

City/Country:	Las Vegas/USA
Airport/Airport Code:	Las Vegas McCarran International Airport/LAS
System Name:	C Gates Tram, D Gates Tram
Role:	Airside conveyance
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	No impact on airport MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	C Gates – 1985, D Gates – 1998
Supplier:	Bombardier
Model:	C/CX-100
System Operating Configuration:	Dual-lane shuttles, elevated and tunnel
Guideway Length:	C Gates – 0.2 miles (0.4 km) dual-lane guideway, D Gates – 0.6 miles (1.0 km) dual-lane guideway
Vehicles Per Train:	C Gates: two; D Gates: three
Fleet Size:	10 vehicles, two two-vehicle trains and two three-vehicle trains
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	Fully automated, solid state
Peak Hour Capacity:	C Gates - 7,200 pphpd, D Gates – 6,600 pphpd
Peak Hour Headway:	C Gates – 1.3 minutes, D Gates – 2.5 minutes
Comments:	A third airside shuttle (tunnel) system is currently being built by Bombardier to serve the E Gates (Terminal 3) and is expected to be operating in 2011, with two three-vehicle trains.



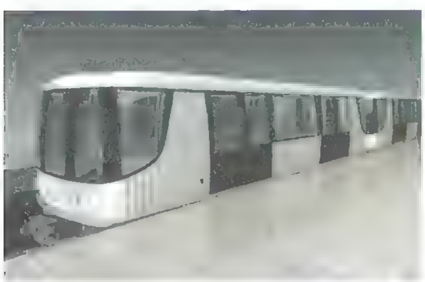
London Gatwick

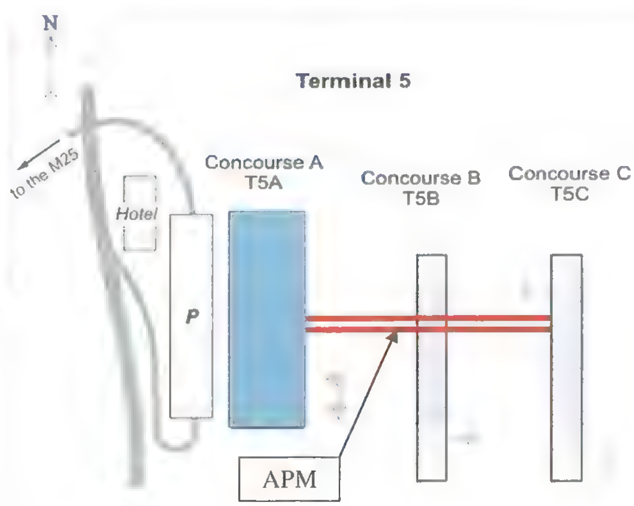
City/Country:	West Sussex/United Kingdom
Airport/Airport Code:	London Gatwick Airport/LGW
System Name:	Gatwick Airport Transit
Role:	Landside conveyance, connects the north and south terminals to rail/bus/road
Benefit:	Enables the airport to process more transfer passengers and reduces congestion on the terminal roadways
Impact on MAP:	Positive impact on O&D MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	1987
Supplier:	Bombardier
Model:	C-100
System Operating Configuration:	Dual-lane shuttle, elevated
Guideway Length:	0.7 miles (1.2 km) dual-lane guideway
Vehicles Per Train:	Three
Fleet Size:	Two three-vehicle trains
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	Fully automated, solid state
Peak Hour Capacity:	4,200 pphpd
Peak Hour Headway:	2.6 minutes
Comments:	Plans for system replacement are currently underway.



London Heathrow

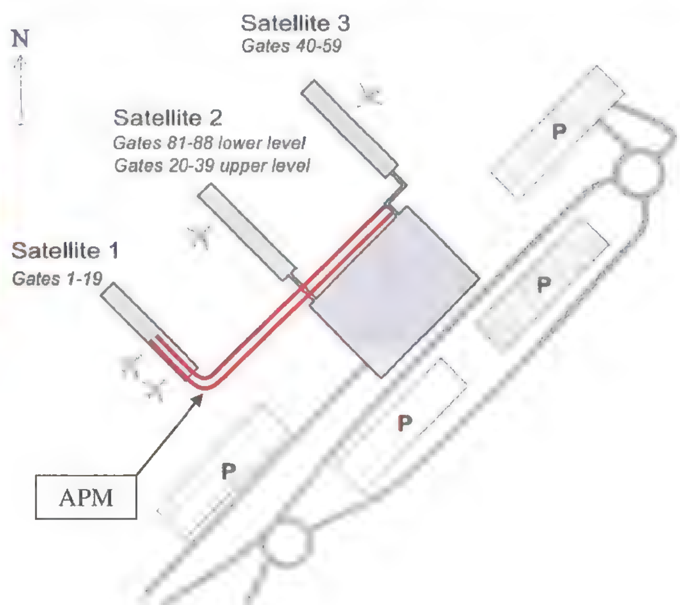
City/Country:	Middlesex/United Kingdom
Airport/Airport Code:	London Heathrow Airport/LHR
System Name:	Tracked Transit System (TTS)
Role:	Airside conveyance
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	2008
Supplier:	Bombardier
Model:	Innovia
System Operating Configuration:	Dual-lane shuttle, underground
Guideway Length:	0.4 miles (0.7 km) dual-lane guideway
Vehicles Per Train:	Three
Fleet Size:	Two three-vehicle trains
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	CITYFLO 650 moving block automated train control
Peak Hour Capacity:	6,500 pphpd
Peak Hour Headway:	1.5 minutes





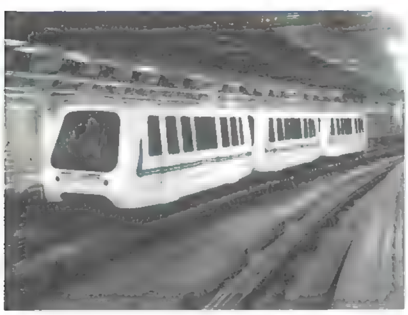
London Stansted

City/Country:	Essex/United Kingdom
Airport/Airport Code:	London Stansted Airport/STN
System Name:	Airport Transit System
Role:	Airside conveyance
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	1991
Supplier:	Bombardier
Model:	C/CX-100
System Operating Configuration:	Pinched loop, elevated and underground
Guideway Length:	0.4 miles (0.6 km) dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	Four two-vehicle trains with one extra vehicle
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	Automated, relay-based fixed block
Peak Hour Capacity:	3,200 pphpd
Peak Hour Headway:	3.0 minutes



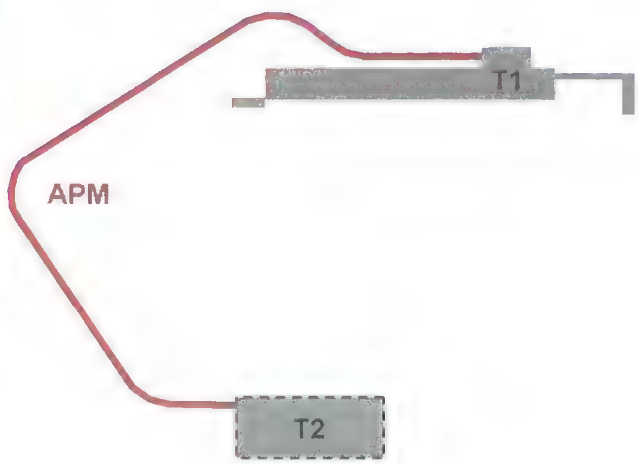
Madrid

City/Country:	Madrid/Spain
Airport/Airport Code:	Madrid Barajas Airport/MAD
System Name:	Unknown
Role:	Airside conveyance, transports passengers between the new terminal (T4) and the new satellite terminal (T4S)
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	2006
Supplier:	Bombardier
Model:	CX-100
System Operating Configuration:	Pinched loop, underground
Guideway Length:	1.4 miles (2.2 km) dual-lane guideway
Vehicles Per Train:	Three initially, expandable to four
Fleet Size:	Six three-vehicle trains with one extra vehicle
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	CITYFLO 550 microprocessor-based fixed block
Peak Hour Capacity:	6,500 pphpd
Peak Hour Headway:	2.0 minutes



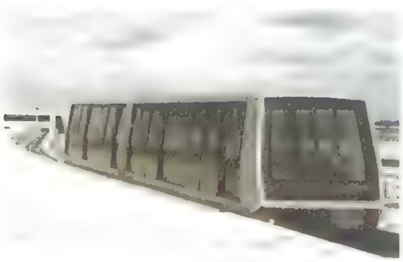
Mexico City

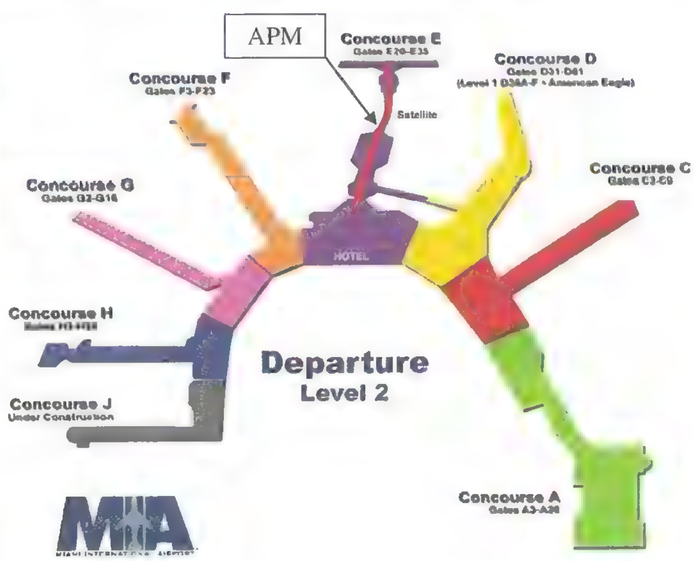
City/Country:	Mexico City/Mexico
Airport/Airport Code:	Mexico City Benito Juarez International Airport/MEX
System Name:	Aerotrén
Role:	Connects Terminal 1 to Terminal 2
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP, positive impact on O&D MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	DCC Doppelmayr Car S.A. de C.V.
In Service Year:	2007 (system completed testing, ridership to begin when Terminal 2 opens)
Supplier:	DCC Doppelmayr
Model:	Cable Liner Shuttle
System Operating Configuration:	Single-lane, elevated
Guideway Length:	1.9 miles (3.0 km) single-lane guideway
Vehicles Per Train:	Four
Fleet Size:	One four-vehicle train
Propulsion:	Cable-propelled, 600 Volts; 60 Hertz
Control System:	Fully automated, based on fail-safe PLC technology
Peak Hour Capacity:	540 pphpd
Peak Hour Headway:	11.2 minutes



Miami

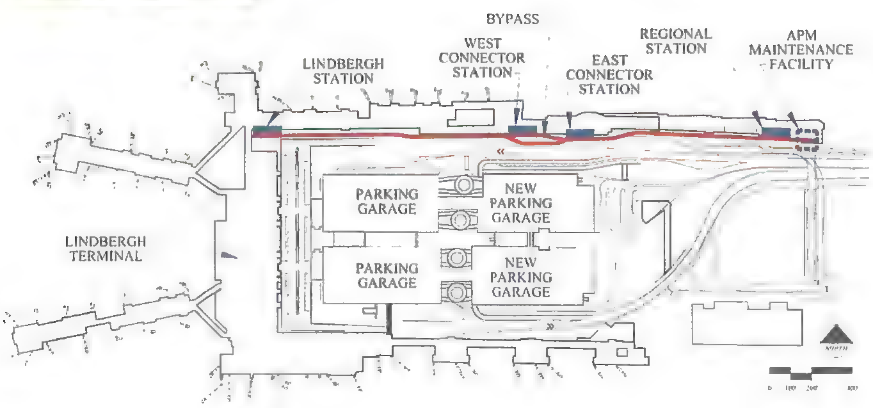
City/Country:	Miami/USA
Airport/Airport Code:	Miami International Airport/MIA
System Name:	Concourse E shuttle
Role:	Airside conveyance, connects main terminal to satellite international terminal
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Johnson Controls
In Service Year:	1980
Supplier:	Bombardier
Model:	C-100
System Operating Configuration:	Dual-lane shuttle, elevated
Guideway Length:	0.2 miles (0.3 km) dual-lane guideway
Vehicles Per Train:	Three
Fleet Size:	Two three-vehicle trains
Propulsion:	DC traction motors, 480 Vac supply guideway-mounted power rail
Control System:	Fully automated, solid state
Peak Hour Capacity:	6,750 pphpd
Peak Hour Headway:	2.0 minutes
Comments:	One lane of the dual-lane shuttle is out of service (2009) and will be replaced.





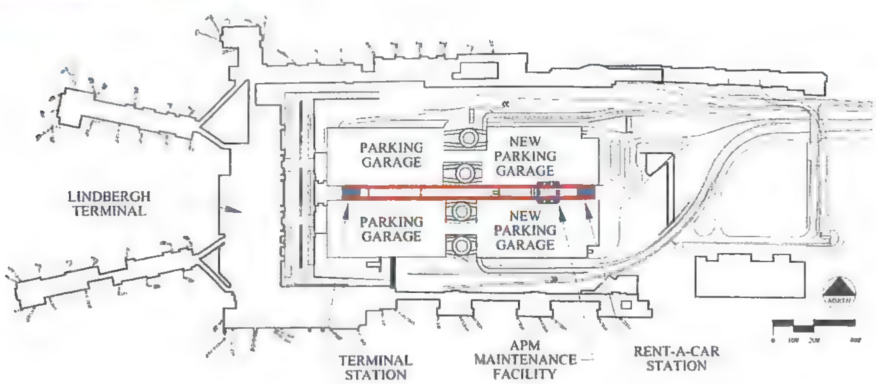
Minneapolis/St. Paul Airside

City/Country:	Minneapolis/USA
Airport/Airport Code:	Minneapolis/St. Paul International Airport/MSP
System Name:	Concourse Tram
Role:	Airside conveyance, connects the Lindbergh Main Terminal and concourses A and B, moves passengers within concourse C
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Schwager Davis, Inc. (SDI)
In Service Year:	2004
Supplier:	Poma-Otis
Model:	Poma 2000, 4-door, 30' vehicles, steel wheel on steel rail
System Operating Configuration:	Pinched loop, elevated
Guideway Length:	0.5 miles (0.8 km) dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	Two two-vehicle trains
Propulsion:	Cable-propelled
Control System:	Automatic, PLC control of cable drive
Peak Hour Capacity:	1,700 pphpd
Peak Hour Headway:	3.1 minutes



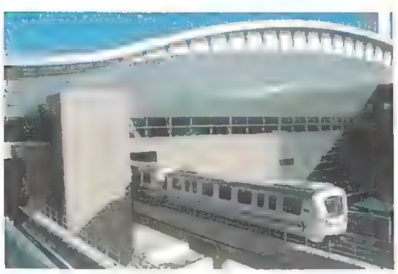
Minneapolis/St. Paul Landside

City/Country:	Minneapolis/USA
Airport/Airport Code:	Minneapolis/St. Paul International Airport/MSP
System Name:	HubTram
Role:	Landside conveyance, connects the terminal to car rental, transit center, light rail station, parking and the Skyway Connector moving walkway
Benefit:	Reduces O&D parking demand and airport roadway congestion
Impact on MAP:	No impact on airport MAP
Impact on Trip Time:	No impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Schwager Davis, Inc. (SDI)
In Service Year:	2001
Supplier:	Poma-Otis
Model:	6-door, 42' vehicles, Hovair ®
System Operating Configuration:	Dual-lane shuttle, underground
Guideway Length:	0.2 miles (0.4 km) dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	Two two-vehicle trains
Propulsion:	Cable-propelled, electric
Control System:	Automatic, PLC control of cable drive
Peak Hour Capacity:	5,200 pphpd
Peak Hour Headway:	1.4 minutes

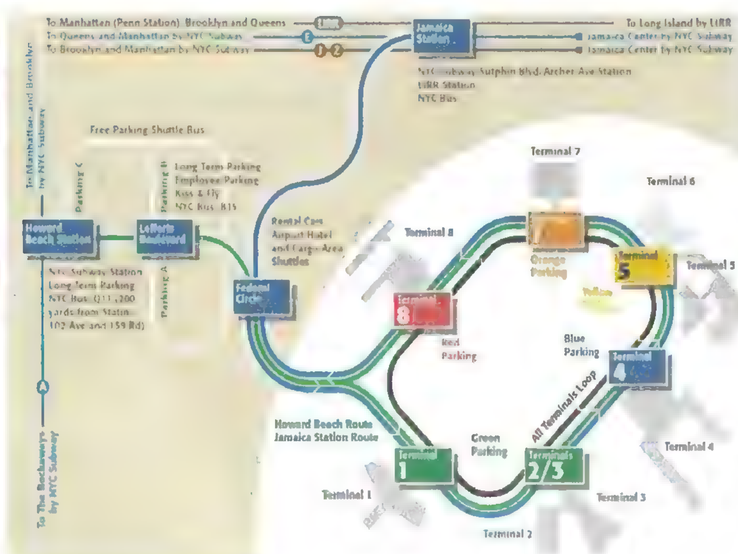


New York–JFK

City/Country:	Jamaica/USA
Airport/Airport Code:	New York–John F. Kennedy International Airport/JFK
System Name:	AirTrain JFK
Role:	Landside conveyance, connects 10 elevated stations and links all terminals with two branches that interface with New York's regional transit systems
Benefit:	Reduces O&D parking demand and airport roadway congestion
Impact on MAP:	Positive impact on O&D MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	2003
Supplier:	Bombardier
Model:	Advanced Rapid Transit (ART) MkII
System Operating Configuration:	Pinched loop, primarily elevated
Guideway Length:	8.1 miles (13.0 km) dual-lane guideway
Vehicles Per Train:	One on CTA, two on Jamaica and Howard Beach
Fleet Size:	32 vehicles
Propulsion:	750 Vdc; third rail, LIM
Control System:	Automated, Seltrac communication-based moving block train control
Peak Hour Capacity:	CTA Loop: 3780 pphpd; Jamaica: 3780 pphpd; Howard Beach: 3780 pphpd
Peak Hour Headway:	CTA Loop: 2.0 minutes: Jamaica and Howard Beach: 4.0 minutes

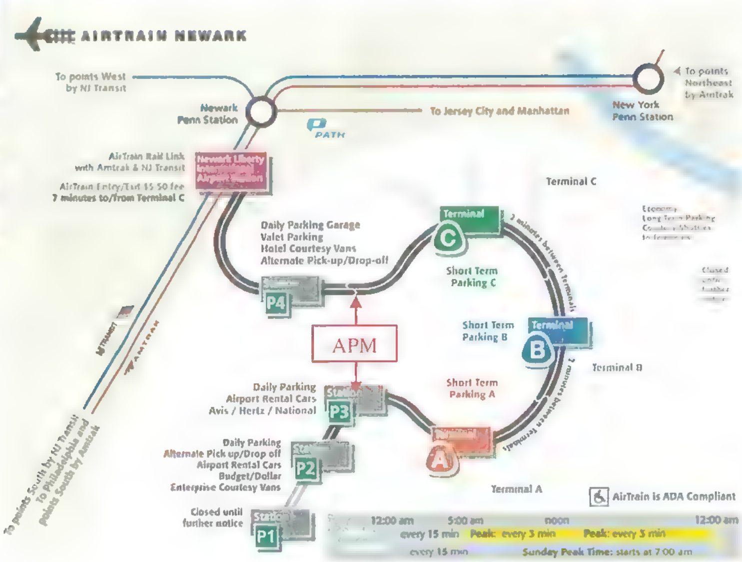


BOMBARDIER



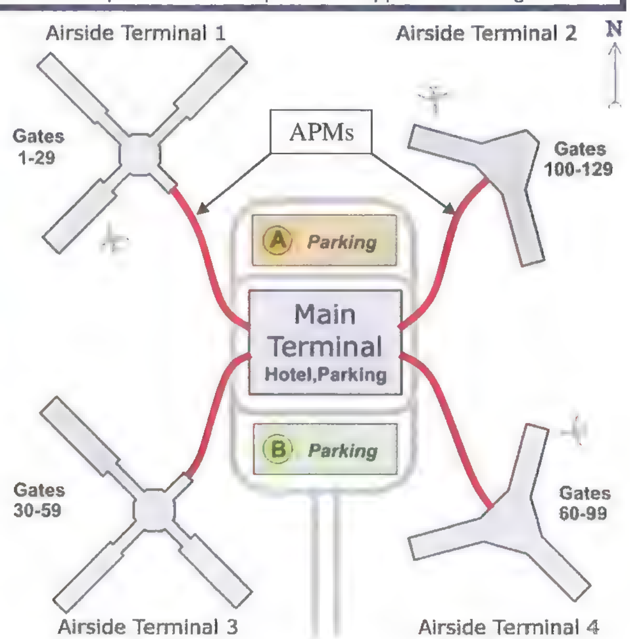
Newark

City/Country:	Newark/USA
Airport/Airport Code:	Newark Liberty International Airport/EWR
System Name:	AirTrain Newark
Role:	Landside conveyance, connects terminals A, B, and C to car park (short and long term), car rental, and regional rail station
Benefit:	Reduces O&D parking demand and airport roadway congestion
Impact on MAP:	Positive impact on transfer MAP, positive impact on O&D MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	1996
Supplier:	Bombardier
Model:	Type IIIa Monorail
System Operating Configuration:	Pinched loop, elevated
Guideway Length:	3.2 miles (5.1 km) dual-lane guideway
Vehicles Per Train:	Six
Fleet Size:	14 six-vehicle trains
Propulsion:	Traction motors, guideway mounted power rail
Control System:	Microprocessor-based fixed block SELTrac-FB in which the vehicle has a digital map of the track layout
Peak Hour Capacity:	2,100 pphpd
Peak Hour Headway:	2.1 minutes
Comments:	System opened in 1996 and was extended 1.1 miles in 2001 to connect with a regional rail intermodal station.



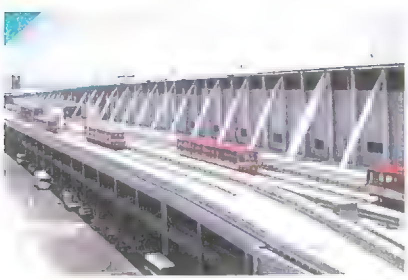
Orlando

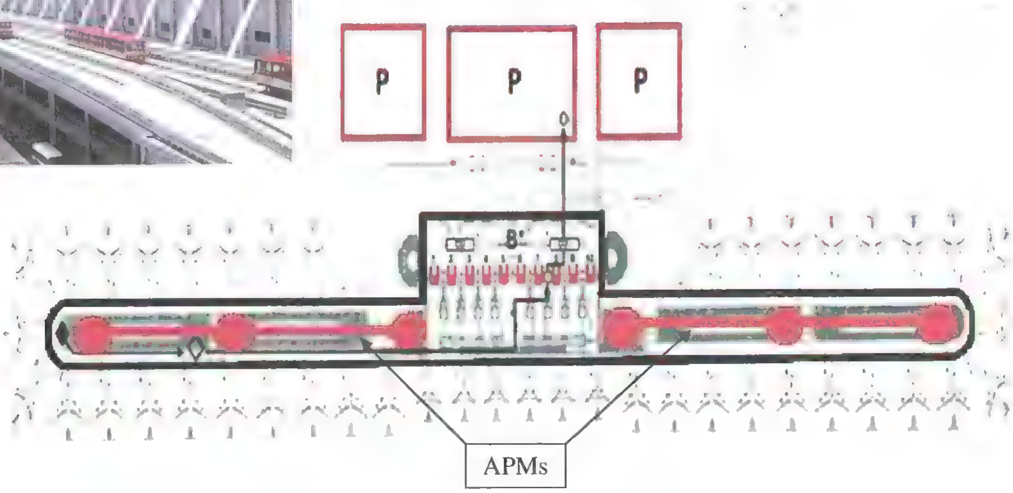
City/Country:	Orlando/USA
Airport/Airport Code:	Orlando International Airport/MCO
System Name:	Automated People Mover System
Role:	Airside conveyance
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	No impact on airport MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	1981 (Airsides 1 & 3)
Supplier:	Bombardier
Model:	CX-100
System Operating Configuration:	Four dual-lane shuttles, elevated
Guideway Length:	1.5 miles (2.4 km) dual-lane guideway (combined length of four shuttles)
Vehicles Per Train:	Three
Fleet Size:	Eight three-vehicle trains
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	Fully automated, solid state
Peak Hour Capacity:	6,000 pphpd
Peak Hour Headway:	2.1 minutes
Comments:	The airport has plans to implement an additional APM to connect the existing terminal with a future South Terminal Complex. Approximately half of the 8,000-foot elevated guideway structure has been constructed. This structure was designed to be compatible with multiple APM supplier technologies.



Osaka Kansai

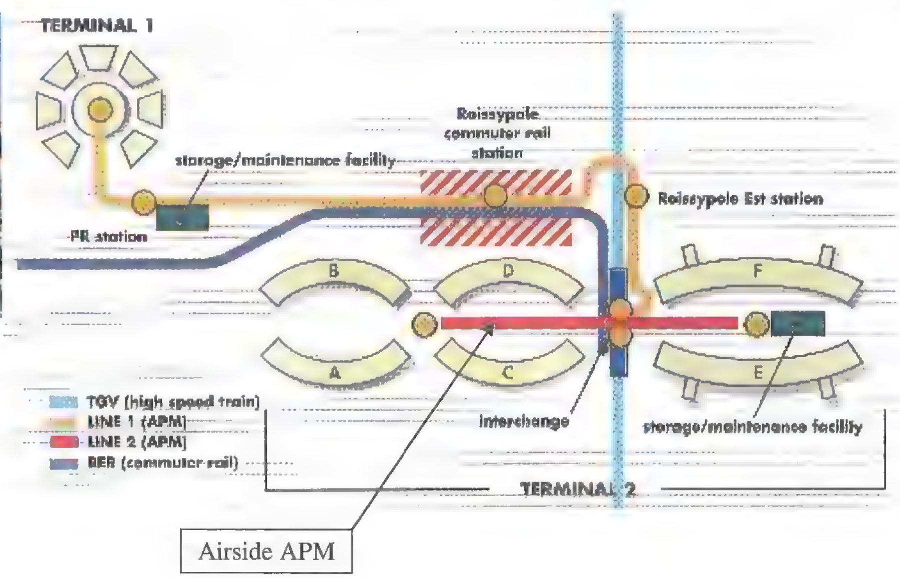
City/Country:	Osaka/Japan
Airport/Airport Code:	Kansai International Airport/KIX
System Name:	Wing Shuttle
Role:	Airside conveyance, transports international passengers from main terminal to gates
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Kansai International Airport
In Service Year:	1994
Supplier:	Niigata/Kawasaki
Model:	Japanese standard technology
System Operating Configuration:	Four single-lane shuttles with bypasses, elevated
Guideway Length:	1.4 miles (2.2 km) single-lane guideway with four bypasses
Vehicles Per Train:	Three
Fleet Size:	Nine three-vehicle trains
Propulsion:	600 Vac traction motors, guideway-mounted power rail
Control System:	Automated, microprocessor-based fixed block
Peak Hour Capacity:	14,400 pphpd
Peak Hour Headway:	2.0–2.5 minutes





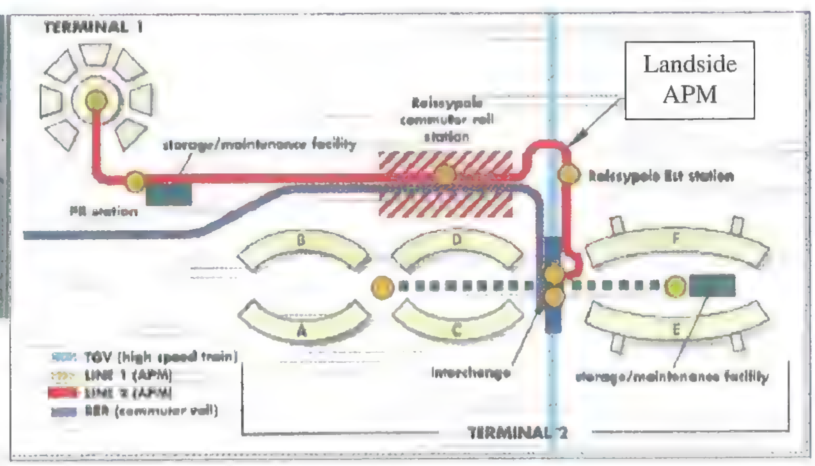
Paris–CDG Airside

City/Country:	Roissy Charles de Gaulle/France
Airport/Airport Code:	Paris Roissy Charles de Gaulle Airport/CDG
System Name:	LISA
Role:	Airside conveyance, links Terminal 2E and Satellite S3
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Aérosat, a joint subsidiary of Keolis and Siemens TS
In Service Year:	2007
Supplier:	Siemens
Model:	VAL 208
System Operating Configuration:	Shuttle, underground
Guideway Length:	0.4 miles (0.6 km) dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	Three two-vehicle trains
Propulsion:	Electric traction motors
Control System:	Automated, fixed block
Peak Hour Capacity:	4,500 pphpd
Peak Hour Headway:	2.0 minutes



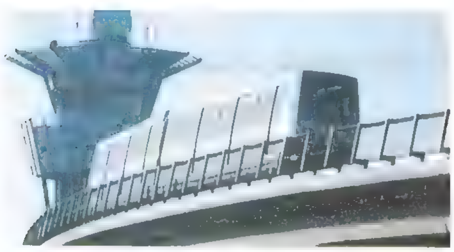
Paris–CDG Landside

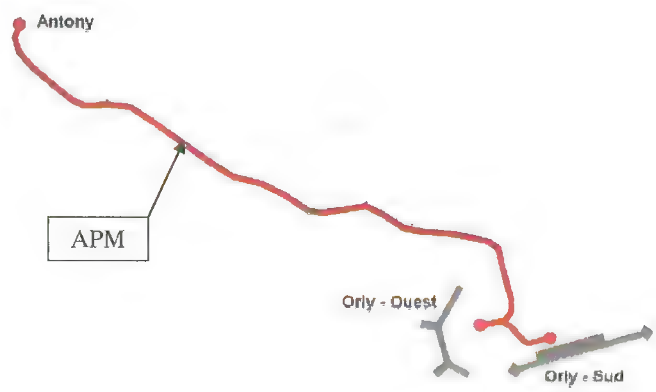
City/Country:	Roissy Charles de Gaulle/France
Airport/Airport Code:	Paris Roissy Charles de Gaulle Airport/CDG
System Name:	CDGVAL
Role:	Landside conveyance, links the three airport terminals, remote parking, high-speed train station and the commuter rail station serving Paris
Benefit:	Reduces O&D parking demand and airport roadway congestion
Impact on MAP:	Positive impact on O&D MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Aérosat, a joint subsidiary of Keolis and Siemens TS
In Service Year:	2007
Supplier:	Siemens
Model:	VAL 208
System Operating Configuration:	Pinched loop, elevated
Guideway Length:	2.1 miles (3.3 km) dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	Seven two-vehicle trains
Propulsion:	Electric traction motors
Control System:	Automated, fixed block
Peak Hour Capacity:	1,900 pphpd
Peak Hour Headway:	4.0 minutes



Paris–Orly

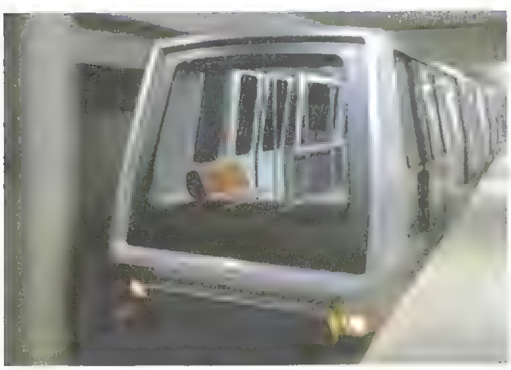
City/Country:	Orly Aérogare/France
Airport/Airport Code:	Paris Orly Airport/ORY
System Name:	OrlyVal
Role:	Landside system connects the south and west terminals to the Antony station of RER B line
Benefit:	Reduces O&D parking demand and airport roadway congestion
Impact on MAP:	Positive impact on O&D MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	RATP
In Service Year:	1991
Supplier:	Siemens
Model:	VAL 206
System Operating Configuration:	Elevated and underground
Guideway Length:	4.5 miles (7.3 km) dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	Eight two-vehicle trains
Propulsion:	VDC Electric Traction Motors
Control System:	Automated, Fixed Block
Peak Hour Capacity:	1,500 pphpd
Peak Hour Headway:	4.0 minutes

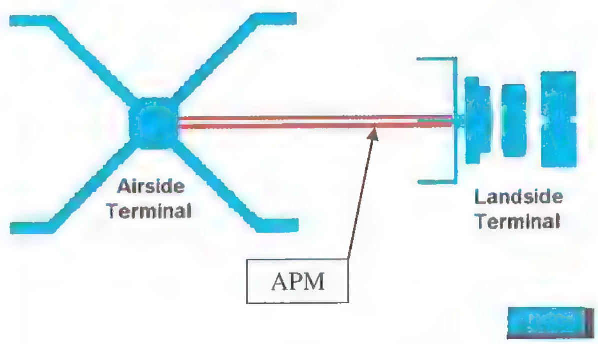




Pittsburgh

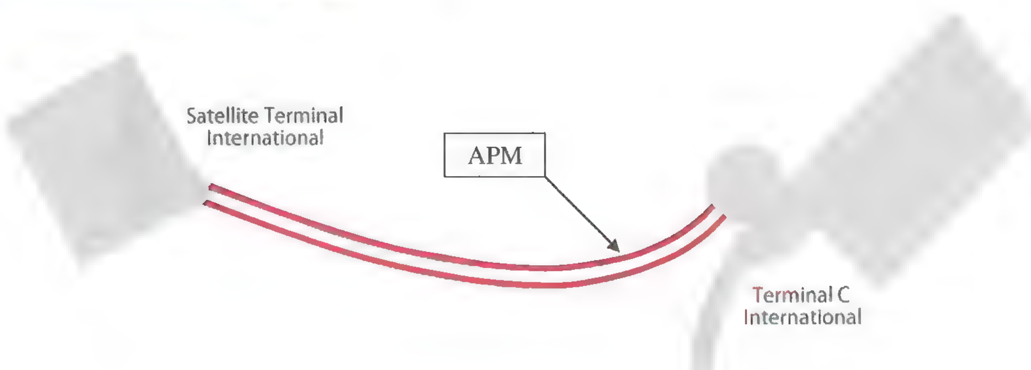
City/Country:	Pittsburgh/USA
Airport/Airport Code:	Pittsburgh International Airport/PIT
System Name:	People Mover
Role:	Airside conveyance
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	1992
Supplier:	Bombardier
Model:	CX-100
System Operating Configuration:	Dual-lane shuttle, underground
Guideway Length:	0.4 miles (0.7 km) dual-lane guideway
Vehicles Per Train:	Three
Fleet Size:	Two three-vehicle trains
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	Fully automated, solid state
Peak Hour Capacity:	8,500 pphpd
Peak Hour Headway:	1.6 minutes





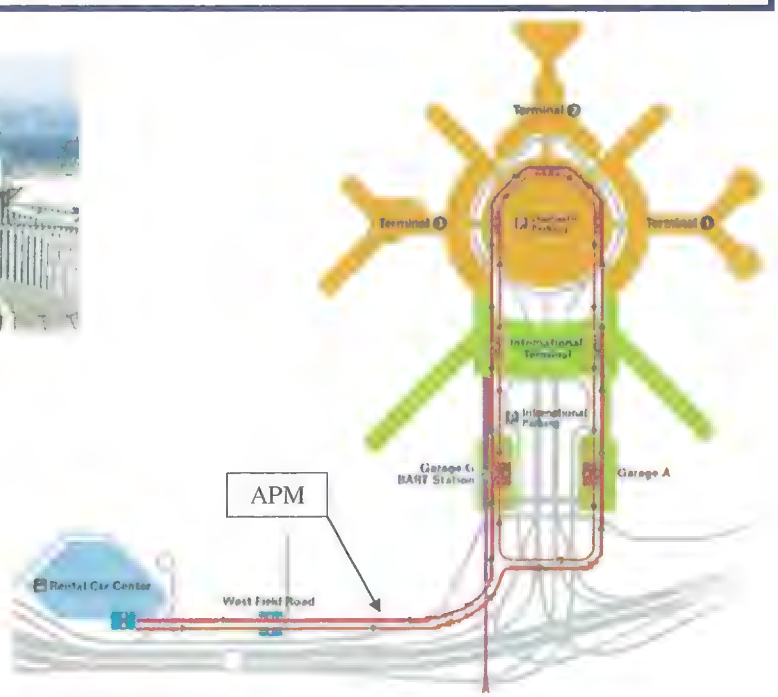
Rome Leonardo da Vinci

City/Country:	Fiumicino/Italy
Airport/Airport Code:	Rome Leonardo da Vinci Fiumicino Airport/FCO
System Name:	SkyBridge
Role:	Airside conveyance, connects the international satellite terminal to Terminal C
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	1999
Supplier:	Bombardier
Model:	CX-100
System Operating Configuration:	Dual-lane shuttle, elevated, able to be converted to pinched loop
Guideway Length:	0.4 miles (0.6 km) dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	Two two-vehicle trains
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	CITYFLO 550 microprocessor-based fixed block
Peak Hour Capacity:	5,300 pphpd
Peak Hour Headway:	1.7 minutes



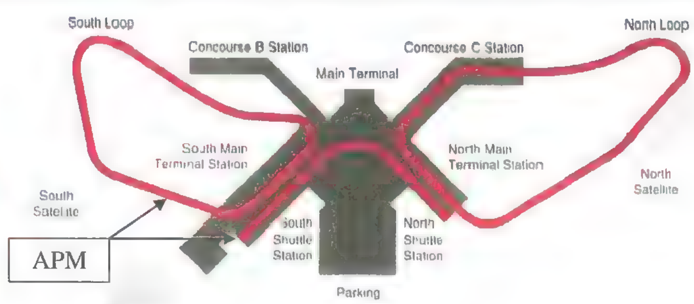
San Francisco

City/Country:	San Francisco/USA
Airport/Airport Code:	San Francisco International Airport/SFO
System Name:	AirTrain
Role:	Landside conveyance, connects terminal to car hire and remote and daily parking and the BART regional rail system
Benefit:	Reduces O&D parking demand and airport roadway congestion
Impact on MAP:	Positive impact on transfer MAP, positive impact on O&D MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	2003
Supplier:	Bombardier
Model:	CX-100
System Operating Configuration:	Two independent single-lane loops, elevated
Guideway Length:	2.8 miles (4.5 km) dual-lane guideway
Vehicles Per Train:	Three
Fleet Size:	38 vehicles
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	CITYFLO 650 moving block automated train control
Peak Hour Capacity:	3,400 pphpd
Peak Hour Headway:	2.5 minutes



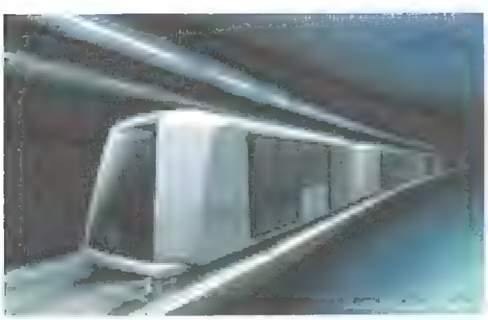
Seattle

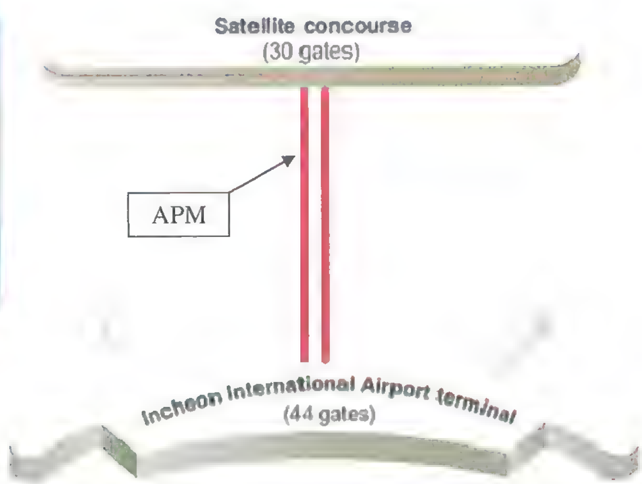
City/Country:	Seattle/USA
Airport/Airport Code:	Seattle–Tacoma International Airport/SEA
System Name:	Satellite Transit System (STS)
Role:	Airside conveyance, connects main terminal to two satellite concourses and two other concourses
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Port of Seattle
In Service Year:	1973, replaced in 2004
Supplier:	Bombardier
Model:	C-100, STS-100 (modified, shortened CX-100)
System Operating Configuration:	Two loops and one shuttle, underground
Guideway Length:	1.7 miles (2.7 km)
Vehicles Per Train:	Three on loop routes, one on shuttle routes
Fleet Size:	21 vehicles
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	CITYFLO 650 moving block automated train control
Peak Hour Capacity:	North Loop: 7,500 pphpd South Loop: 7,500 pphpd North/South Shuttle: 1,200 pphpd
Peak Hour Headway:	North Loop: 1.7 minutes South Loop: 1.7 minutes North/South Shuttle: 2.0 minutes
Comments:	North and south loops are normally operated with two three-vehicle trains to avoid trains stopping outside the station in the event the train ahead is delayed for any reason.



Seoul

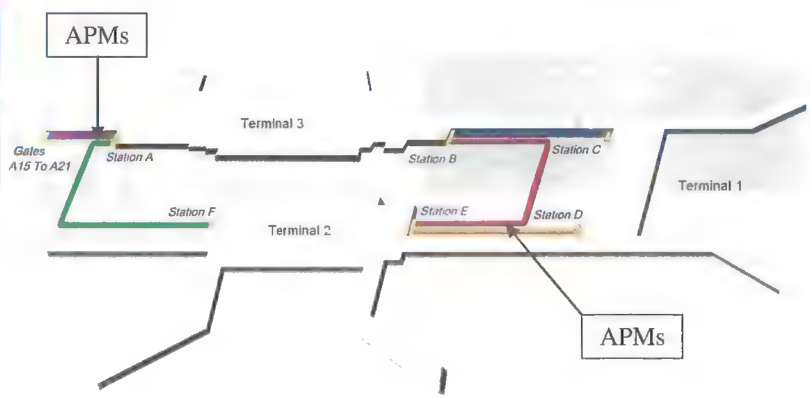
City/Country:	Seoul/South Korea
Airport/Airport Code:	Incheon International Airport/IIA
System Name:	Intra Airport Transit System (IAT) "Starline"
Role:	Airside conveyance, transports passengers between Terminal 1 and Concourse A
Benefit:	Allows airport to operate with significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Airport
In Service Year:	2008
Supplier:	Mitsubishi Heavy Industries
Model:	Crystal Mover
System Operating Configuration:	Dual-lane shuttle, underground
Guideway Length:	0.6 miles (0.9 km) dual-lane guideway
Vehicles Per Train:	Three
Fleet Size:	Three three-vehicle trains
Propulsion:	VVVF inverter vector control
Control System:	Automated, microprocessor-based fixed block
Peak Hour Capacity:	5,184 pphpd
Peak Hour Headway:	2.5 minutes





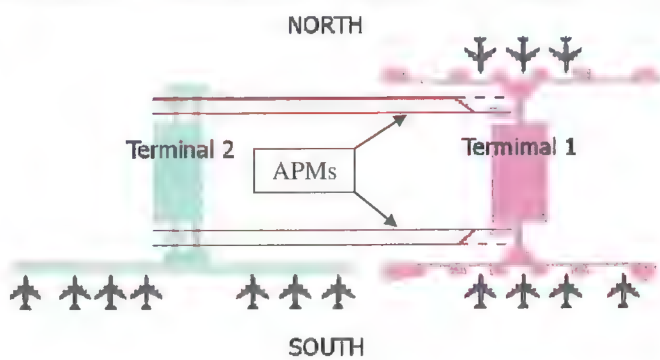
Singapore Changi

City/Country:	Singapore
Airport/Airport Code:	Singapore Changi Airport/SIN
System Name:	Skytrain
Role:	Airside and landside conveyance, interconnects terminals T1, T2, and T3
Benefit:	Allows airport to operate with a significantly larger number of gates and reduces O&D parking demand and airport roadway congestion
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Mitsubishi
In Service Year:	2006
Supplier:	Mitsubishi Heavy Industries
Model:	Crystal Mover
System Operating Configuration:	Seven shuttles – single-lane shuttles (two airside, two landside), dual-lane shuttles (one airside) and bypass shuttles (one airside, one airside/landside combo) (elevated)
Guideway Length:	1.5 miles dual-lane guideway (combined equivalent)
Vehicles Per Train:	One and two
Fleet Size:	16 vehicles
Propulsion:	VVVF inverter vector control
Control System:	Automated, microprocessor-based fixed block
Peak Hour Capacity:	A-A: 2,077; A-F: 1,117 pphpd; B-C Airside: 982 pphpd; B-C Landside: 926 pphpd; B-E Airside/Landside: 1,940 pphpd; D-E Airside: 953 pphpd; D-E Landside: 771 pphpd
Peak Hour Headway:	A-A: 1.3 minutes; A-F: 2.4 minutes; B-C Airside: 2.75 minutes; B-C Landside: 2.9 minutes; B-E Airside/Landside: 2.8 minutes; D-E Airside: 2.8 minutes; D-E Landside: 3.5 minutes
Comments:	Replaced the original T1-T2 Bombardier C-100 airside/landside shuttles plus added T1-T3 and T2-T3 shuttles.



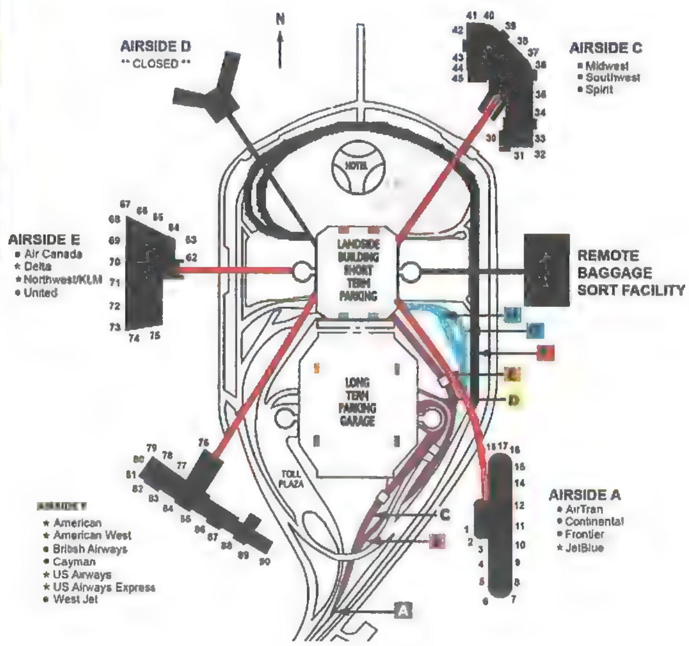
Taipei

City/Country:	Taipei/Taiwan, Republic of China
Airport/Airport Code:	Taiwan Taoyuan International Airport/TPE
System Name:	Skytrain
Role:	Transports secure and non-secure passengers between Terminal 1 & 2
Benefit:	Reduces O&D parking demand and airport roadway congestion and allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Taiwan Taoyuan International Airport
In Service Year:	2003
Supplier:	Niigata
Model:	New Transportation System (NTS)
System Operating Configuration:	Two dual-lane shuttles w/crossover, elevated
Guideway Length:	0.8 miles (1.3 km) single-lane guideway
Vehicles Per Train:	One and two
Fleet Size:	Six vehicles
Propulsion:	600 Vac traction motors, guideway mounted power rail
Control System:	Automated, fixed block
Peak Hour Capacity:	6,000 pphpd
Peak Hour Headway:	2.0 minutes



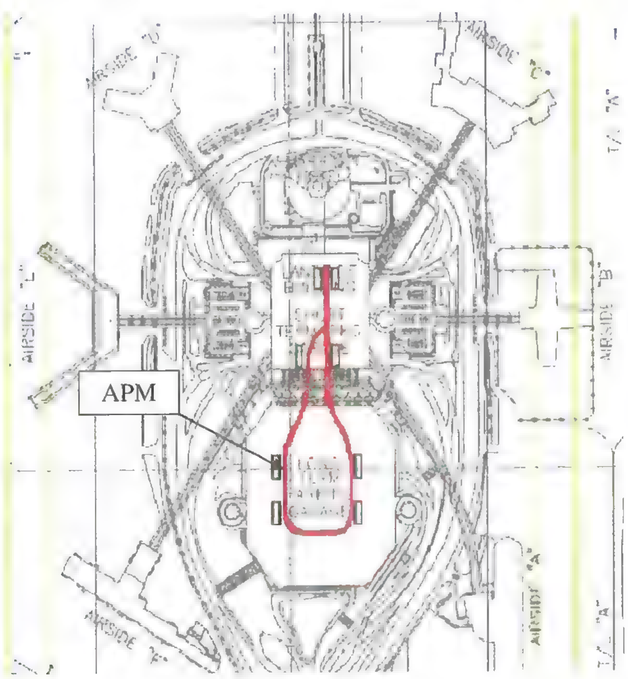
Tampa Airside

City/Country:	Tampa/USA
Airport/Airport Code:	Tampa International Airport/TPA
System Name:	Airport People Mover
Role:	Airside conveyance, connects main terminal to four satellite terminals
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	No impact on airport MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	1971
Supplier:	Bombardier
Model:	C/CX-100
System Operating Configuration:	Dual-lane shuttles, elevated
Guideway Length:	0.7 miles (1.2 km) combined dual-lane guideways for legs A,C,E, & F
Vehicles Per Train:	Two
Fleet Size:	16 vehicles
Propulsion:	DC traction motors, 600 Vac supply guideway-mounted power rail
Control System:	Fully automated, solid state
Peak Hour Capacity:	A: 5,745 pphpd; C: 6,429 pphpd; E: 7,013 pphpd; F: 6,207 pphpd
Peak Hour Headway:	A: 1.7 minutes; C: 1.4 minutes; E: 1.3 minutes; F: 1.5 minutes



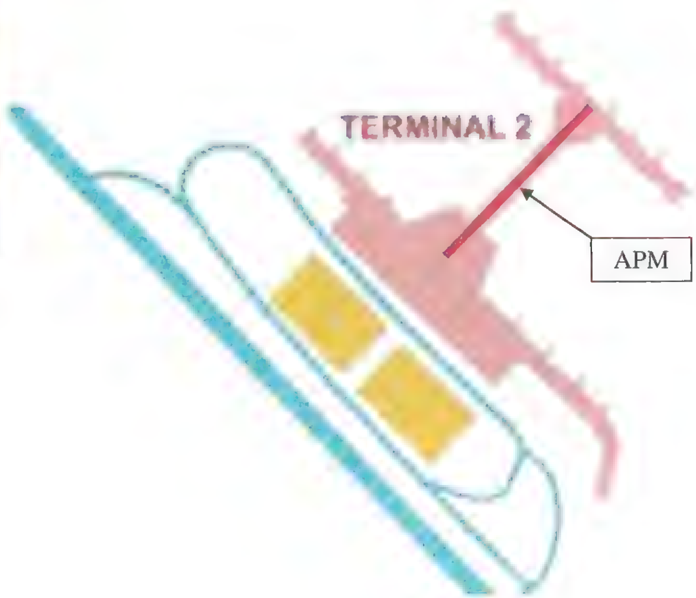
Tampa Landside

City/Country:	Tampa/USA
Airport/Airport Code:	Tampa International Airport/TPA
System Name:	Garage Monorail
Role:	Landside conveyance, serves short- and long-term parking and car hire
Benefit:	Reduces O&D parking demand and airport roadway congestion
Impact on MAP:	No impact on airport MAP
Impact on Trip Time:	No impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Bombardier Transportation
In Service Year:	1990
Supplier:	Bombardier
Model:	UM-III monorail
System Operating Configuration:	Pinched loop, low profile guideway attached to garage floor
Guideway Length:	0.6 miles (1 km) single-lane guideway
Vehicles Per Train:	One
Fleet Size:	Six one-vehicle trains
Propulsion:	480 Vac power, DC traction motors, guideway mounted power rail
Control System:	Automated, microprocessor-based fixed block
Peak Hour Capacity:	700 pph
Peak Hour Headway:	1.5 minutes



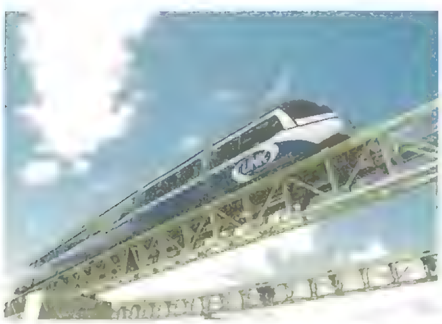
Tokyo Narita

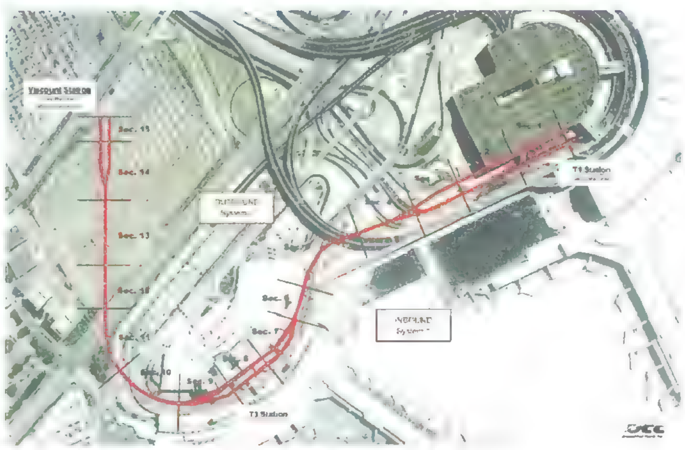
City/Country:	Chiba/Japan
Airport/Airport Code:	Tokyo Narita Airport/NRT
System Name:	Terminal 2 Shuttle System
Role:	Airside conveyance, connects the main terminal to the satellite terminal
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Nippon Otis
In Service Year:	1992
Supplier:	Nippon Otis Elevator
Model:	Hovair
System Operating Configuration:	Two single-lane shuttles with bypasses, elevated
Guideway Length:	0.2 miles (0.3 km) dual-lane guideway
Vehicles Per Train:	One
Fleet Size:	Four one-vehicle trains
Propulsion:	Cable-propelled, electric
Control System:	Power modulation in acceleration and braking, fully automated wayside control
Peak Hour Capacity:	9,800 pphpd
Peak Hour Headway:	1.8 minutes



Toronto

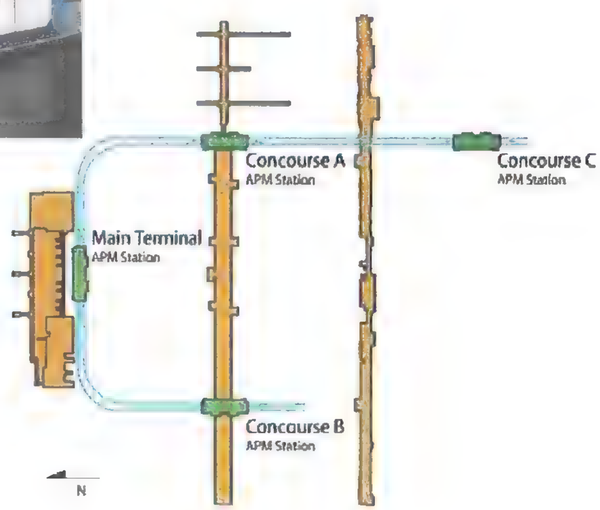
City/Country:	Toronto/Canada
Airport/Airport Code:	Toronto Pearson International Airport/YYZ
System Name:	The LINK
Role:	Landside conveyance between Terminal 1, Terminal 3, airport hotel, parking, employee parking lot, and future connection to regional rail
Benefit:	Reduces airport roadway congestion, more reliable and cost-effective than bussing
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Doppelmayr GmbH
In Service Year:	2006
Supplier:	Doppelmayr GmbH
Model:	Cable Liner Shuttle
System Operating Configuration:	Dual-lane shuttle, elevated
Guideway Length:	0.9 miles (1.5 km) dual-lane guideway
Vehicles Per Train:	Six
Fleet Size:	Two six-vehicle trains
Propulsion:	Cable-propelled, 600 Volts; 60 Hertz (Siemens AC motors and Simovert drives)
Control System:	Fully automated, based on fail-safe PLC technology
Peak Hour Capacity:	2,150 pphpd
Peak Hour Headway:	4.0 minutes
Comments:	A new 8,000-car garage will be opening near the APM's Viscount station and will serve both airline passengers and airport employees.





Washington Dulles

City/Country:	Dulles/USA
Airport/Airport Code:	Washington Dulles International Airport/IAD
System Name:	AeroTrain APM System
Role:	Airside conveyance, connects main terminal and two remote concourses
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Crystal Mover Services Inc.
In Service Year:	2010
Supplier:	Mitsubishi Heavy Industries
Model:	Crystal Mover
System Operating Configuration:	Pinched loop, underground
Guideway Length:	1.5 miles (2.3 km) dual-lane guideway
Vehicles Per Train:	Three
Fleet Size:	29 vehicles
Propulsion:	AC traction motors, 750 Vdc power, guideway-mounted power rail
Control System:	Automatic Train Control System, SelTrac® by Thales
Peak Hour Capacity:	6,755 pphpd
Peak Hour Headway:	2.0 minutes



Zurich

City/Country:	Zurich/Switzerland
Airport/Airport Code:	Zurich Airport/ZRH
System Name:	Skymetro
Role:	Airside conveyance, connects the main terminal to the satellite terminal
Benefit:	Allows airport to operate with a significantly larger number of gates
Impact on MAP:	Positive impact on transfer MAP
Impact on Trip Time:	Positive impact on transfer trip time, positive impact on O&D trip time
Operating Entity:	Otis
In Service Year:	2003
Supplier:	Poma-Otis
Model:	Hovair
System Operating Configuration:	Pinched loop, underground
Guideway Length:	0.7 miles (1.1 km) dual-lane guideway
Vehicles Per Train:	Two
Fleet Size:	Three two-vehicle trains
Propulsion:	Cable-propelled, electric
Control System:	Fully automated, based on a fail-safe PLC technology
Peak Hour Capacity:	4,500 pphpd
Peak Hour Headway:	2.5 minutes

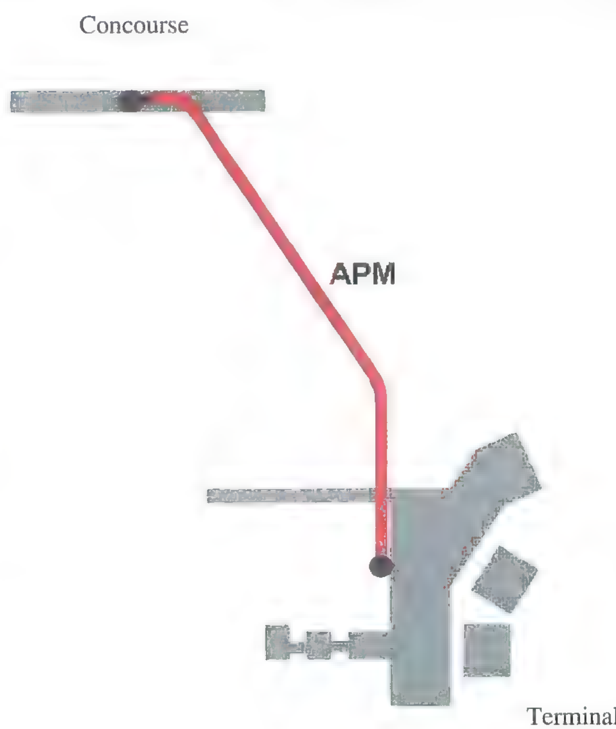


Image References

1. **Atlanta Airside**
   Image 1 (lower left): www.bombardier.com
   Image 2 (lower right): City of Atlanta Department of Aviation
2. **Atlanta Landside**
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   Image 2: City of Atlanta Department of Aviation
3. **Beijing Airside**
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4. **Birmingham**
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5. **Chicago**
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   Image 2 (lower right): Chicago Airport System
6. **Cincinnati**
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   Image 2 (lower right): Kenton County Airport Board
7. **Dallas/Fort Worth**
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8. **Denver**
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9. **Detroit**
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10. **Düsseldorf**
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    Image 2(lower right): Bombardier C-100 and CX-100 System Data Sheets.pdf
12. **Hong Kong**
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13. **Houston Airside**
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14. **Houston Landside**
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15. **Kuala Lumpur**
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18. **London Heathrow**
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    Image 2 (lower right): Aena (Airport Operator)
21. **Mexico City**
    Image 1 (lower left): www.dcc.at/
    Image 2 (lower right): Grupo Aeroportuario de la Ciudad de México (Airport Group of Mexico City)
22. **Miami**
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    Image 2 (lower right): Miami-Dade Aviation Department (MDAD)
23. **Minneapolis/St. Paul Airside**
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    Image 2 (lower right): Minneapolis/Saint Paul Metropolitan Airports Commission
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    Image 2 (lower right): Minneapolis/Saint Paul Metropolitan Airports Commission
25. **New York–JFK**
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    Image 2 (lower right): Port Authority of New York and New Jersey
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28. **Osaka Kansai**
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29. **Paris Charles de Gaulle Airside**
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    Image 2 (lower right): Bombardier brochure on SEA
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37. **Singapore Changi**
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38. **Taipei**
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43. **Washington Dulles**
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Image 2: Metropolitan Washington Airport Authority (MWAA)
44. **Zurich**
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Image 2 (lower right): Flughafen Zürich

APPENDIX C

Glossary

Air levitation: A type of APM train support along the guideway.

Airside: The area or side of an airport that is secure, in that all passengers and employees have gone through a security check to enter this area.

APM: *See* automated people mover.

APM platform: The barrier wall, door sets, and passenger queuing area within the APM station and adjacent to the APM train or vehicle berthing position.

ATC: *See* automatic train control.

ATO: *See* automatic train operation.

ATP: *See* automatic train protection.

ATS: *See* automatic train supervision.

Automated people mover (APM): Fully automated and driverless transit systems that operate on fixed guideways in exclusive rights of way.

Automatic station platform doors: The station doors that are automatically controlled and synchronized with train dwells. When closed, the doors are part of a barrier between the passengers and the trains operating on the guideway.

Automatic train control (ATC): The APM subsystem that coordinates and controls all operations of the APM system including train movements, switching, vehicle and station door openings, and communications.

Automatic train operation (ATO): Performs basic operating functions within the safety constraints imposed by the ATP.

Automatic train protection (ATP): Functions to ensure absolute enforcement of safety criteria and constraints. It provides the basic safety functions of the system and typically includes safe spacing of trains (loop or pinched-loop systems), overspeed protection, switch controls, and door controls.

Automatic train supervision (ATS): Provides for system supervision by central control computers and permits manual interventions/overrides by central control operators using control interfaces.

Baggage carts: Four-wheeled wagons that are typically rented at airports to carry the luggage of arriving or departing passengers on airport property. Commonly referred to in Europe as trolley carts.

Cable-propelled vehicles: APM vehicles that are propelled via a cable along the guideway. Typically the vehicles are permanently attached to a cable.

CCF: *See* Central control facility.

Central control facility (CCF) (also called central control or central control room): A building or rooms in which the central control operators perform their tasks and duties; typically houses the system schematic display, the power schematic display, the general system display, the central control console, and related ATC, communications, and control equipment.

Center platform configuration: An APM platform configuration in which a single platform is located between the two (opposite direction) guideway lanes. Both the alighting and boarding of trains occur on this single platform.

Connecting airline: The operation of a single airline at a particular airport where multiple aircraft arrive and a large percentage of arriving airline passengers then proceed to a departing aircraft. Also referred to as hubbing airline.

Connecting passenger: An airline passenger who arrives at a given airport via an arriving flight and then connects to a departing flight at the same airport. Also referred to as transfer passenger.

Consist: The vehicles making up a train. (This term comes from the railroad industry and means the rolling stock, exclusive of the locomotive, making up a train.)

Contiguous terminal configuration: An airport terminal design in which both passenger processing functions (ticketing, security, baggage claim) and the aircraft gates are under one roof.

Dual-lane shuttle: An APM system alignment configuration in which two trains shuttle back and forth independently on independent guideways usually in synchronized fashion.

Dynamic passenger information: Part of the APM system's communications package, this electronic signage assists passengers using the system by providing information regarding train destinations, door status, and other operational information.

Facilities: The buildings, rooms, and guideway that house or physically support the APM's operating system equipment.

Flow-through platform: A three-platform station configuration in which the two side platforms accommodate alighting passengers while the center platform accommodates boarding passengers.

Geometric constraints: The horizontal and vertical geometric limits used in designing an APM guideway to help ensure rider safety and comfort.

Guidebeams: A physical beam that is secured into the guideway that guides the APM train.

Guideway: The track or other riding surface that supports APM trains as they move between stations.

Hubbing airline: The operation of a single airline at a particular airport where multiple aircraft arrive and a large percentage of arriving airline passengers then proceed to a departing aircraft. Also referred to as connecting airline.

Landside: The non-secure side of the airport where functions such as ticketing, bag claim, parking, and car rental take place.

Loop configuration: An APM system alignment that allows multiple stations to be served with a self-propelled vehicle fleet.

Magnetic levitation: A means that suspends, guides, and propels APM vehicles using electromagnetic force.

Maintenance and storage facility (MSF): The location for all vehicle maintenance and storage, as well as associated maintenance equipment and administrative offices.

MSF: *See* maintenance and storage facility.

Offline maintenance facility: A mainline facility that is located outside of the APM system's operational guideway. APM trains are removed from operational service and positioned in the maintenance facility where maintenance service is then performed.

Online maintenance facility: A maintenance facility that is located such that vehicles positioned to receive maintenance services are also located on passenger-carrying guideway, typically at a station. Maintenance is performed during non-operational hours of the APM system.

Operating system: The proprietary subsystem equipment of an APM supplier that is essential to the APM system's operation.

Origin/destination (O/D) passengers: Airline passengers who either start their trip at the particular airport in question (origin) or end their trip at that airport (destination).

Passengers per hour per direction (pphpd): A common passenger capacity metric used in APM and other airport analysis.

Personal rapid transit (PRT): A type of automated transit system that is on-demand, uses an exclusive right-of-way, provides point-to-point service, and usually accommodates no more than three to four passengers per vehicle.

Pinched loop: An APM system configuration in which trains travel in a loop by reversing direction via switches at the end-of-line stations.

Platform configuration: The number of platforms and their passenger functionality at a given station.

Power distribution rails: Rails along the APM guideway that supply power to self-propelled APM trains.

pphpd: *See* passengers per hour per direction.

PRT: *See* personal rapid transit.

Remote terminal configuration: An airport terminal design configuration in which passenger processing functions occur in a separate facility from the facility that houses the aircraft gates.

Self-propelled vehicles: APM vehicles that include propulsion, braking, and automatic control systems on the vehicle itself.

Side guidance rails: Guidance rails located along the exterior or side of the guideway running surface that help to keep the APM train aligned as it moves along the guideway.

Single-lane shuttle: An APM alignment configuration in which a single train shuttles back and forth between two end stations on a single guideway.

Single-lane shuttle with bypass: An APM alignment configuration in which two synchronized trains pass each other in the bypass area (centrally located) of the guideway.

Single side platform: an APM platform configuration in which boarding/deboarding occur on one side of the guideway.

Train control: The APM subsystem that includes command, control, and communications equipment needed to operate the driverless vehicles.

Transfer passenger: An airline passenger who arrives at a given airport via an arriving flight and then transfers to a departing flight at the same airport. Also referred to as a connecting passenger.

Transit connection: An intermodal connection (station) between an airport's landside APM and a regional bus and/or rail transit service.

Triple platform: An APM platform configuration in which two side platforms and one center platform serve the station's two guideway lanes. Typically passenger alighting occurs to the side platforms and boarding occurs from the center platform.

Two side platforms: An APM platform configuration in which boarding/deboarding occurs on either of two platforms, both located at the exterior of the two parallel guideway lanes.

Vehicle: The individual unit or car that includes the carbody together with appropriate systems.

APPENDIX D

Annotated Bibliography of Codes and Standards

The following is an annotated bibliography of the agencies whose codes and standards affect APM systems at airports in the United States.

ANSI

The American National Standards Institute (ANSI) oversees the creation, promulgation, and use of thousands of norms and guidelines that directly impact businesses in nearly every sector of technology. ANSI is also actively engaged in accrediting programs that assess conformance to standards—including globally recognized cross-sector programs such as the ISO 9000 (quality) and ISO 14000 (environmental) management systems.

ANSI standards are used in the APM industry for electrical design and vibration testing as well as for cranes, hoists, and lifts. In addition, many of the other standards listed for APM systems are recognized as ANSI standards or are in the process of gaining such recognition.

Some of their applicable standards include:

- Practices and Requirements for Semiconductor Power Rectifiers
- Application Guide for AC Hi-Voltage Circuit Breakers Rated on a Symmetrical Current Basis
- Low-Voltage Power Circuit Breakers and AC Power Circuit Protectors, Preferred Ratings, Related Requirements and Application Recommendations

AREMA

The American Railway Engineering and Maintenance-of-Way Association (AREMA) recommends practices pertaining to the design, construction, and maintenance of railway infrastructure throughout North America, including rail transit systems.

AREMA standards are used in the APM industry for software safety design philosophy and critical component failure analyses. Also, many APM train control designs are derived from AREMA train control standards and their predecessors. In certain cases, the APM industry substitutes AREMA cable standards in lieu of TIA standards. The *Manual for Railway Engineering* is one of their applicable publications.

ASCE

The American Society of Civil Engineers (ASCE) has created and published ASCE Standard 21 (Automated People Mover Standards). This standard has been prepared by the ASCE Automated People Movers Standards Committee. The standard is developed by a consensus standard process managed by ASCE's Codes and Standards Committee. The Automated People Movers Standards Committee includes members representing a balanced combination of APM consumers, producers, regulators, and general interest. The overall goal of this standard is to assist the industry and the public by establishing standards for APM systems. It establishes the minimum set of requirements for the design, construction, operation, and maintenance of APM systems necessary to achieve an acceptable level of safety and performance for an APM system. As such, it may be used to identify the minimum requirements for the safety certification process.

This standard has been divided into four parts to expedite the approval and release process as well as to facilitate ease of use. Parts 1, 2, and 3 cover a minimum set of requirements for design of an automated people mover with an acceptable level of safety and performance. Part 4 is a minimum set of requirements for maintaining an acceptable level of safety and performance for an automated people mover in passenger operation.

ASHRAE

The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) develops standards for both its members and others professionally concerned with refrigeration processes and the design and maintenance of indoor environments. ASHRAE writes standards for the purpose of establishing consensus for: (1) methods of test for use in commerce and (2) performance criteria to guide the industry. ASHRAE publishes the following three types of voluntary consensus standards: Method of Measurement or Test, Standard Design, and Standard Practice.

ASHRAE standards are used in the APM industry for heating, ventilation, and air conditioning (HVAC) units, energy conservation, and determination of extreme weather conditions in the United States.

Some of their applicable standards and publications include:

- *ASHRAE Handbook—HVAC Systems and Equipment*
- ASHRAE Standard 90-75—Energy Conservation in New Building Design

ASTM

ASTM International, formerly known as the American Society for Testing and Materials (ASTM), is one of the largest voluntary standards development organizations in the world—a trusted source for technical standards for materials, products, systems, and services. ASTM International standards have an important role in the information infrastructure that guides design, manufacturing, and trade in the global economy.

ASTM standards are used by the APM industry in the specification of steel and other metals, structural steel elements, fasteners, cement, and concrete reinforcement. ASTM standards are also used for testing of materials, flammability/toxicity testing, and environmental testing of equipment.

Some of their applicable standards include:

- Specification for Structural Steel
- Specification for High Strength Bolts for Structural Steel
- Specification for Lead-Coated and Lead-Alloy-Coated Soft Copper Wire for Electrical Purposes

IEEE

The Institute of Electrical and Electronic Engineers Standards Association (IEEE-SA) is a leading developer of industry standards in a broad-range of industries. The IEEE-SA has strategic relationships with the IEC, ISO, and the ITU and satisfies all SDO requirements set by the World Trade Organization, offering more paths to international standardization.

IEEE standards are used in the APM industry for train control, power distribution systems, motors, grounding, electrical protection, emergency standby power and uninterruptible power supplies, and software design.

Some of their applicable standards include:

- National Electrical Safety Code
- Test Procedures for AC High-Voltage Circuit Breakers
- Standard for Software Configuration Management Plans

TIA

The Telecommunications Industry Association (TIA) is accredited by ANSI to develop voluntary industry standards for a wide variety of telecommunications products. TIA's Standards and Technology Department is comprised of ten technology areas that sponsor more than 70 standard-formulating groups. Each area is represented by engineering committees and subcommittees that formulate standards to serve the industry and users.

TIA standards are used in the APM industry for telecommunication cables, including fiber optics, networking, wiring, rack layouts, and cable terminations.

Some of their applicable standards include:

- Standard Test Procedure for Fiber Optic Fibers, Cables, Transducers, Sensors, Connecting and Terminating Devices, and Other Fiber Optic Components
- Generic Specification for Fiber Optic Cable
- Commercial Building Telecommunications Cabling Standard

NEMA

The National Electrical Manufacturers Association (NEMA) is the trade association of choice for the electrical manufacturing industry. Approximately 450 member companies manufacture products used in the generation, transmission and distribution, control, and end-use of electricity. These products are used in utility, medical imaging, industrial, commercial, institutional, and residential applications.

NEMA standard products are used by the APM industry for electrical breakers and fuses, motors and generators, control cables, switchgear, electrical conduits and fittings, and control and wiring enclosures.

Some of their applicable standards include:

- Fittings, Cast Metal Boxes and Conduit Bodies for Conduit and Cable Assemblies
- High Temperature Instrumentation and Control Cables
- Motors and Generators
- High Voltage Fuses

NFPA

The National Fire Protection Association (NFPA) develops, publishes, and disseminates more than 300 consensus codes and standards intended to minimize the possibility and effects of fire and other risks.

NFPA standards are used by the APM industry for fire detection, fire alarm systems, emergency communication devices, fire extinguishers and fire suppression systems, and electrical protection and lightning protection. NFPA is also the sponsor of the National Electrical Code (NEC) and the National Electrical Safety Code (NESC), which are used worldwide for the installation of electrical devices, equipment, and wiring.

Some of their applicable standards include:

- Electrical Safety Requirements for Employee Workplaces
- Fire Alarm Codes
- Protection of Electronic Computer/Data Processing Equipment
- Lightning Code

APPENDIX E

Modeling

In the current state-of-the-art APM system planning there is a range of modeling tools that are applied during the predesign phase of the work. These tools are all facilitated by computer-based analyses intended to study the operating conditions that the APM system will serve. This appendix addresses the two most common types of computer-based tools—spreadsheets and simulation models.

Effective modeling tools can be spreadsheet based, which in the current state of the art are primarily applied to assess ridership and passenger flow conditions. Spreadsheets can also be applied to approximate train performance and operating conditions, although their use for this aspect is becoming less common. Spreadsheets generally are built around calculations from mathematical methodologies that, for the two types of models discussed herein, are simpler and more static in the conditions analyzed.

Simulation models are computer-based tools that allow a more comprehensive analysis of the complex, dynamic conditions of APM system operations within an airport environment. Such tools simulate the movement of people and APM trains (as well as other transportation elements in the case of landside models) in sequential time steps overall or a portion of the characteristic day being analyzed.

These analytically oriented simulation tools are not to be confused with three-dimensional visualization tools that are intended to primarily provide a lifelike presentation of what the airport APM facilities will look like. Such visualization tools usually do not perform any specific analysis of the type described below for simulation models. That being said, 3-D presentations of simulation model analytical results are becoming more common in the aviation industry, and the use of 3-D visualization software to present the simulation analysis results can be beneficial.

The following descriptions of both spreadsheet and simulation modeling applications provide an overview of the range of analytical results that can be obtained. The discussion of spreadsheets focuses on the modeling of APM system ridership demand and the associated station flows. The simulation modeling discussion describes the modeling of ridership demand, passenger flow through terminal/station facilities, transit user experience, train performance, and system operations.

Overall, the level of detail required in the planning process will be determined by the needs of the study, and the choice of the methodology to calculate station flow will be dictated by the study scope. Generally, the use of some level of spreadsheet applications will be likely for almost every planning study. Frequently, the additional use of simulation models is often warranted as the APM system project progresses through higher levels of advanced planning and concept/schematic design.

Spreadsheet Modeling

The application of spreadsheet tools has been a common practice in the airport planning field over the past twenty-five years. The analytical power of modern spreadsheets has made this a very useful and practical approach to modeling station flows and the resulting design requirements, particularly in the earlier phases of planning. This methodology commonly is used for the modeling of system ridership demands and thus the flows at each system station.

Flight Schedule Processing

The nature of passenger flows within an airport is fundamentally driven by the schedule of flights and the associated enplaning and deplaning activity for the airside concourses for the planning/design day (usually an average day in the peak month). A reasonably detailed flight schedule is prepared in spreadsheet form that represents the number of flight arrivals and departures at a given terminal or concourse within a given period of time. Depending on the level of detail required in the modeling process, the time period increments

can be as small as 1 minute or as large as 1 hour. Further, the incremental part of the airport terminal that is defined for flight arrival and departure may be as small as a single gate or as large as an entire concourse. Variable rates of enplanement and deplanement can be used to define the passenger flows in and out of the airport facilities. Often, the size and complexity of spreadsheet models soon reach a practical limit; thus not all spreadsheets attempt to model a high level of detail.

Passenger Flow Analysis

Once a flight schedule and enplaning/deplaning dataset is defined for the planning day, the spreadsheet model can be expanded to calculate the distribution of the air passenger flows through the airport facilities. Spreadsheet models can encompass airside concourses, the terminal(s), and/or the landside facilities. Depending on the placement of the APM system and its functional purposes within the airport, the simplest models would typically focus on only the part(s) of the airport to be served by the APM system. A time distribution factoring technique is then applied to spread the air passenger activity before the time of enplanements and following the time of deplanements. The time period modeled for the flight activity and for calculating the movement of air passengers through the APM system should be consistent.

The simplest spreadsheet models do not calculate the complete distribution of passenger flows for each flight in small increments of time before and after the flight arrival and departure. Rather, a factoring technique is commonly used to represent typical peaking effects within each hour for the composite of all flight activity. Such peaking factors may be derived from other aspects of the airport planning process, or a similar airport/APM application may be a suitable source of empirical data for determining such time-related flow factors.

In the next level of spreadsheet models, air passenger flows between the points of origin and destination within the airport study area are derived by factoring the flight schedule data portion of the model. This spatial flow factoring is based on information such as (1) the percentage distribution of airport access by mode/landside facilities, (2) the percentage distribution of air passenger utilization of ticketing/baggage check stations and other terminal processing functions, and (3) the distribution of air passengers between airlines and their associated airside concourse inherent to the flight schedule/air passenger activity database.

Once the basic flows of air passengers and the origin/destination trip data are calculated, spreadsheet models then calculate the distribution of other populations that are to be served by the APM. These could be (1) flight crews (with flight schedule related distributions), (2) escort visitors (with flight schedule related distributions), (3) airline/airport employees (with work shift related distributions), and/or (4) other populations at the airport, such as office workers in adjacent buildings.

Once the spreadsheet model accounts for all of the different population movements through the portion of the airport served by the APM, the flow of APM riders passing through each station during all time periods of the day can be estimated. These flows can be calculated for any time period that the base data are suitable to derive. For calculating station flow time periods that are less than the resolution of the base flight schedule data time period(s), the peaking effects can be estimated for planning purposes through the application of peaking factors, as discussed previously.

Station Activity Analysis

The overall APM passenger flow estimating spreadsheet can include separate worksheets to calculate the key aspects of station flows and thus physical requirements. Alternately, separate, smaller spreadsheets can be used for each station. These models are normally developed only for the peak period at each station (which could vary by station) and focus on the following station requirements:

- **Boarding platform occupancy sufficient to establish level-of-service indicators and related minimum platform sizing.** The models would be designed to distribute passengers among the station platform doors, either evenly or in a ratio to the proximity of each door to the entry/exit point(s). The space requirements for queuing at each door area can be calculated using average areas for each rider, which are based on level-of-service spaces from Fruin or other sources, as discussed elsewhere in this guidebook. Given the train lengths determined in separate analysis (see Section 8.3), the spreadsheet calculations can inform the planner if the postulated station queuing area (particularly width) is adequate for the level of service desired or if adjustments are needed.
- **Vertical circulation requirements for sizing elevators, escalators, and stairways.** The spreadsheet model modules (or separate sub-models) can be used to estimate the requirements for these vertical transport devices if they are needed in the station design. Volumes entering and leaving the station and using each entry/exit are estimated from earlier modeling. Assumptions are made concerning the percentage using each type of device. These can be based on data from other airport APM stations or factors used in the overall airport planning effort. Typically 5–10% will use the elevators (disabled and riders with strollers or many bags), another 5–10% the stairs, and the rest the escalators. Factors are available or can be calculated within

the model for elevator speed (car capacity can be a variable based on general station design), escalator capacity per minute (at no less than one passenger every two steps), and stairs. The spreadsheet model can then determine whether an initial set of devices is adequate, or how many are needed. As discussed elsewhere in this guide, spreadsheet models can also be used to calculate the NFPA-130–based (or building code) requirements for emergency egress routes. This could affect the number and sizes of the vertical transport devices in the station.

- **Circulation areas between the vertical transportation elements and the platform doors.** Spreadsheet models can also be used to estimate the width of areas for passenger circulation, given volumes and assumed walking speeds.

The station size and vertical transport devices that result from this modeling are then input to general station design drawings and facility cost estimates.

Spreadsheet models typically allow a reasonable approximation suitable for planning-level studies of APMs, particularly for conditions where the airport or areas served by the APM are not large or the ridership population types are fairly homogeneous. The more complex the composite flows of multiple passenger types and the more refined the time increment and/or the size and complexity of the airport APM application, then the greater the importance of applying a higher level of station flow modeling. Spreadsheets are limited (or at least cumbersome) for parsing the station flow data to the demands on a minute-by-minute basis. If capacity limits appear to be important in station design, spreadsheet models may be insufficient to define the requirements for specific station elements such as platform queuing area and numbers and sizes of vertical circulation elements.

Simulation Modeling

Passenger flow simulation models are often quite sophisticated, and several different models are available from different consulting companies. Generally, airport simulation models are created to represent the spatial areas of the terminal and landside facilities through which passengers, employees, and escort visitors move. Within these spatial models there can be comprehensive representation of the different levels that typically comprise the airport facilities, allowing the complete travel paths of the different populations to be represented. Usually, APM access and station models are only a part of an overall airport terminal model, although simpler simulation models, such as with boundaries at the station entry and exit points, can also be used.

Depending on the capabilities of the simulation tool, the input data can be as fundamental as the entire airport's flight schedule and air passenger enplanement/deplanement data for a given planning/design day. Alternately, the input data may be as extensive as pre-processed passenger flow data derived from spreadsheets that have already calculated basic passenger flows for each APM station. In the former case, the passenger flow models would typically encompass a larger airport-wide scale, and in the latter, the passenger flow models may only encompass the specific station(s) of interest. This range of model applications therefore presents opportunities for alternative levels of combined spreadsheet and simulation model use.

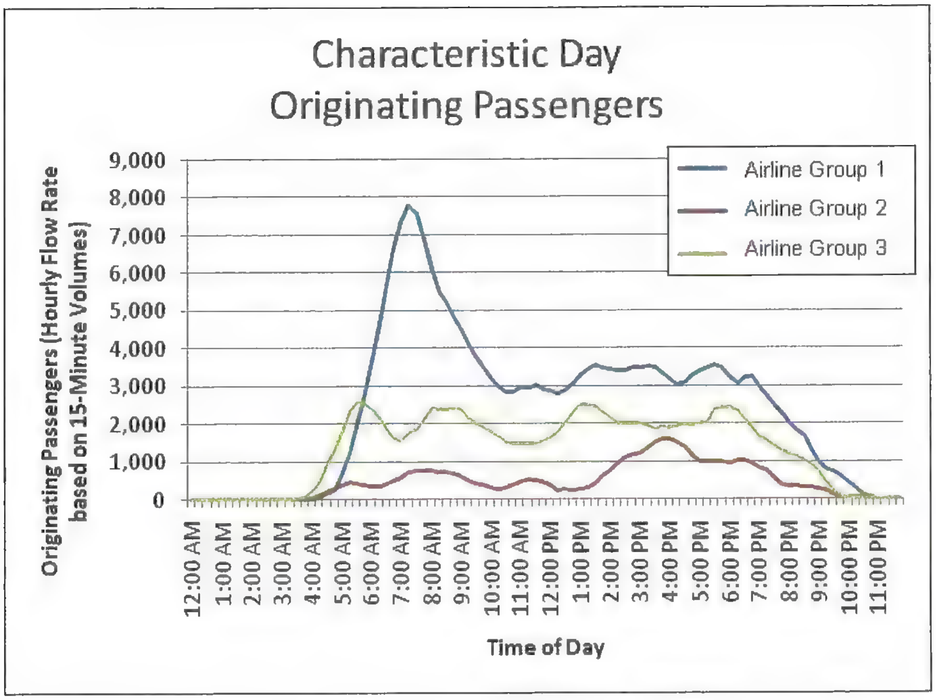
Flight Schedule Processing

As an example, Figure E-1 shows both the originating passenger activity with the associated time distribution for the passengers' early arrival in advance of flight time compared with the corresponding terminating and connecting passenger activity for a given flight schedule. Note how the arrival distribution of the originating passenger is smoothed by the early arrival patterns, whereas the terminating and connecting passenger activity is very spiked in profile due to their immediate entry into the airport facilities upon the flight arriving at the gate. The simulation model's processing of the flight schedule database and the assignment to the passengers' travel paths will reflect these different patterns for originating, terminating and connecting passengers.

APM System Ridership

Depending on the way that these very different activity profiles are assigned onto the APM system (a function of the APM system configuration of terminals, landside elements, and the airside concourses), the simulation model derives the ridership loading on all links of the APM system. Figure E-2 shows the actual APM system ridership for a link that is carrying primarily terminating passengers bound for baggage claim in the terminal—a common point of peak demand conditions for many airport APM systems.

Figure E-3 shows the peak ridership conditions for all links, but with the added precision possible (but not displayed in this figure) of the calculation of the precise time of day for the peak ridership load condition. In the example shown in the figure, each link has its peak five-minute demand condition presented as an equivalent hourly demand—a fairly extreme peaking condition for planning-level analysis purposes. The respective peak demand for each link does not occur at the same time of day, so the data as presented is not in concurrent time between the links. Of course, any other time interval ridership demand analysis can also be conducted with the simulation model, depending on the needs of the planning study and the purposes of the ridership analysis.



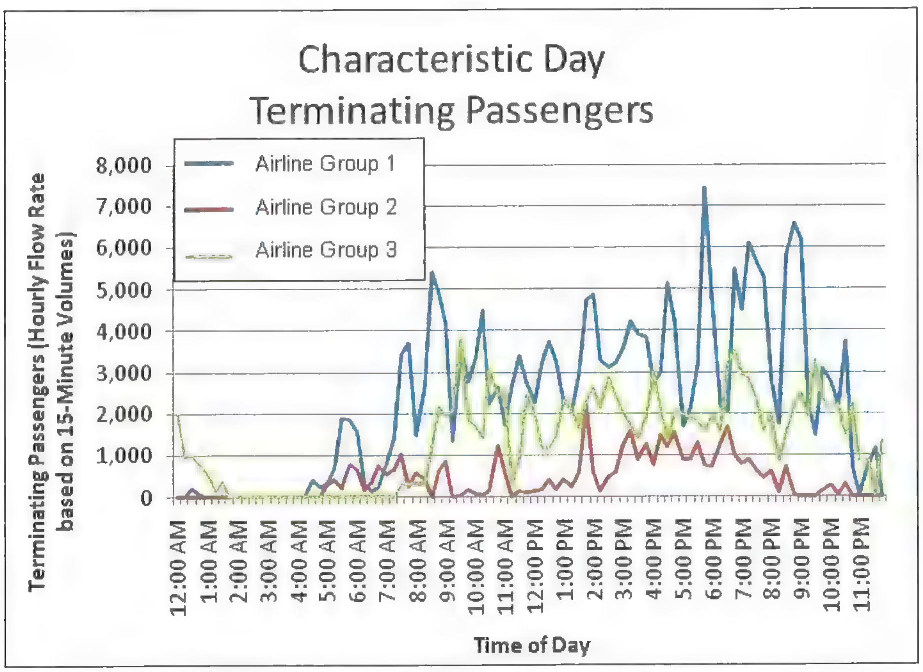


Figure E-1. Passenger trip processing and assignment from the flight schedule.

Station Activity Analysis

When the planning analysis has first predetermined the criteria/goals of the APM system capacity to be provided relative to the peak demand conditions, the simulation modeling tool can then assess the impacts on the passengers waiting in the station, both during the peak demand interval and throughout the day. Figure E-4 shows the results of a simulation model's 24-hour accumulation of station waiting time—i.e., the time until the passenger was able to board a train. As shown in the figure, some stations have conditions where passengers cannot board the first train to arrive in the station and they have to wait for the next train before they can board. This can be caused by either the station having extremely high

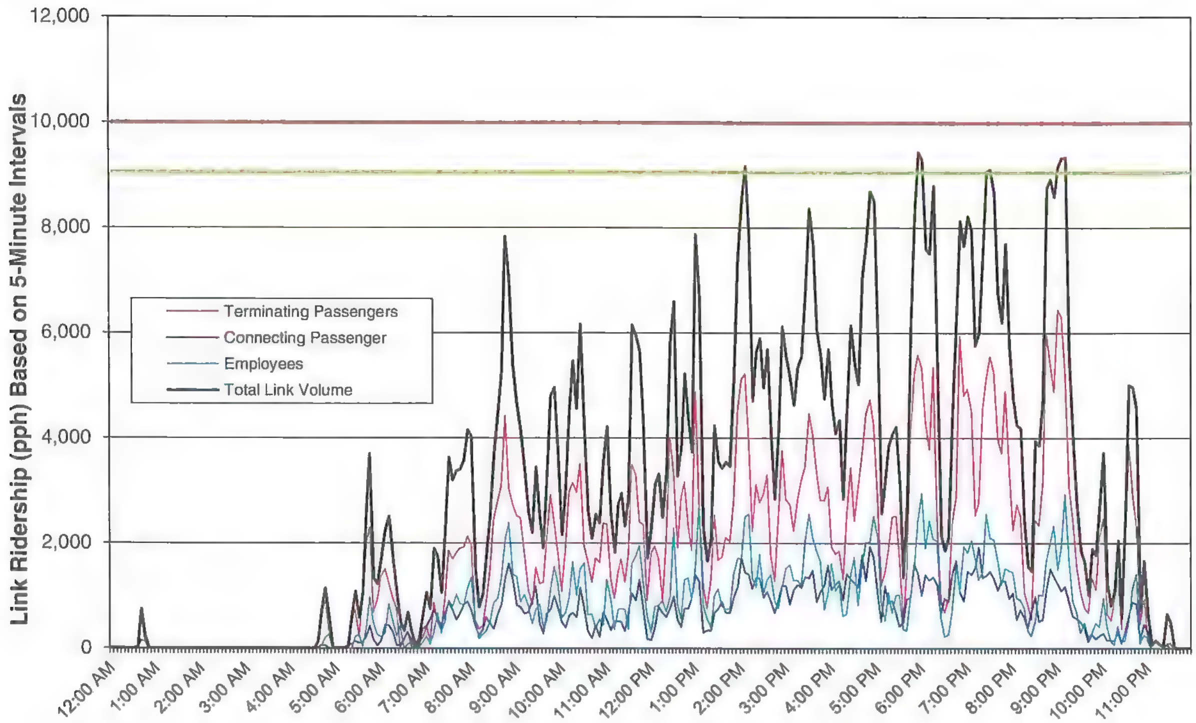


Figure E-2. Typical APM system ridership data from simulation analysis.

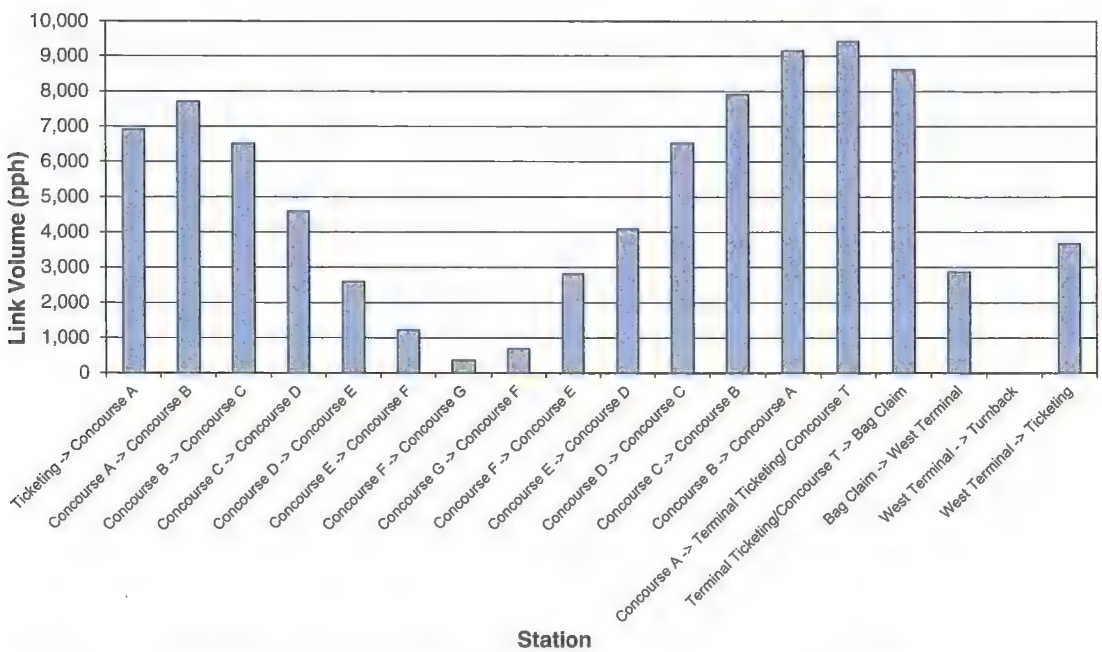


Figure E-3. Peak link volume (pph) equivalent hourly flow rate by station, based on the peak 5-minute interval throughout the day. Link demands can be analyzed by the simulation for precise times of day (equivalent hourly flow rates for peak 5 minute intervals not concurrent in time).

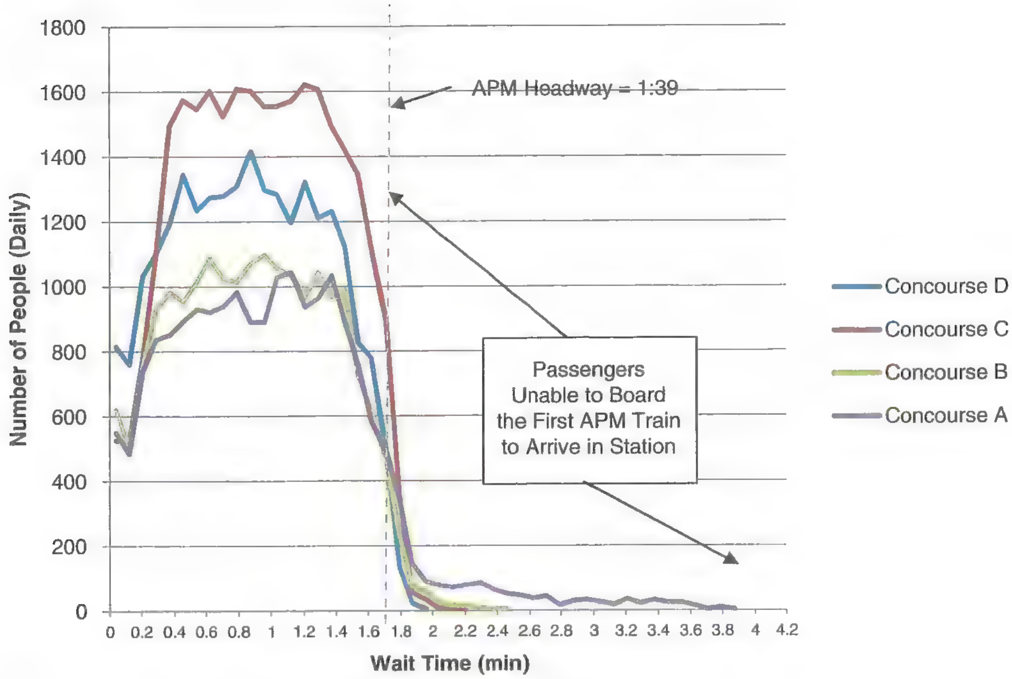


Figure E-4. Station waiting time distribution (APM inbound).

demand during peak intervals and/or the station having a location that is significantly impacted by operating conditions where some trains arrive completely full, not allowing all passengers to board.

Based on the simulated ridership, associated with pedestrian flows and system capacity limitations, models are used to assess the dynamic station operating conditions that result and the related level of service provided within each element of the passenger's travel path—the passenger experience provided by the APM.

For purposes of APM system passenger flow modeling, these travel paths may include considerable details of the station elements, including:

- Access and egress corridor locations and widths;
- Station platform areas and individual boarding areas and locations for each APM vehicle position;
- Numbers, widths, locations, and configurations of escalators;
- Numbers, sizes, locations, and lobby configuration of elevator banks; and
- Numbers, widths, configurations, and locations of stairways.

Figure E-5 shows animated modeling of an APM station at which all passengers alight to travel to baggage claim in the terminal above. As shown in the figure, the surge flow conditions are dramatic, with the full cars arriving at many times of the day. Figure E-6 shows an example of the demand conditions over several hours on a 1-minute time-step basis for the dual escalator set serving the station. The graph and legend clearly indicate the impacts of the heavy surge flows, with flow "In" and flow "Out" being accumulative over the time step, "Volume" being the instantaneous occupancy at the end of the time step, and "PE Volume" being the equivalent number of pedestrians when the additional space claim of their luggage is included. It should also be noted that the flow capacity constraints to escalators is at the point where the pedestrian boards the unit, and this constraint in the simulation caused a bulk queue to build and dissipate over a few moments time whenever the surge flow rates exceeded the capacity of the escalator loading process. As long as the simulation showed that the queue dissipated in a reasonable period of time and in particular the peak-of-peak conditions did not remain until the next train arrived, the vertical circulation system was judged to be adequate for the demands imposed.

The simulation model depictions of the station flow conditions are commonly analyzed for a complete 24-hour day in order to understand the complexities of the demand variations for each flight arrival and departure complex. In large hub airports, these flight complexes often drive unique capacity requirements for each station such that they have peak demands occurring at times of the day that are different from the other stations. For example:

- At stations serving a large component of airport and airline employees, the shift change patterns typically dictate the periods of highest demand;
- At stations serving a particular airside concourse, the flight schedule characteristics of the airline(s) served on that

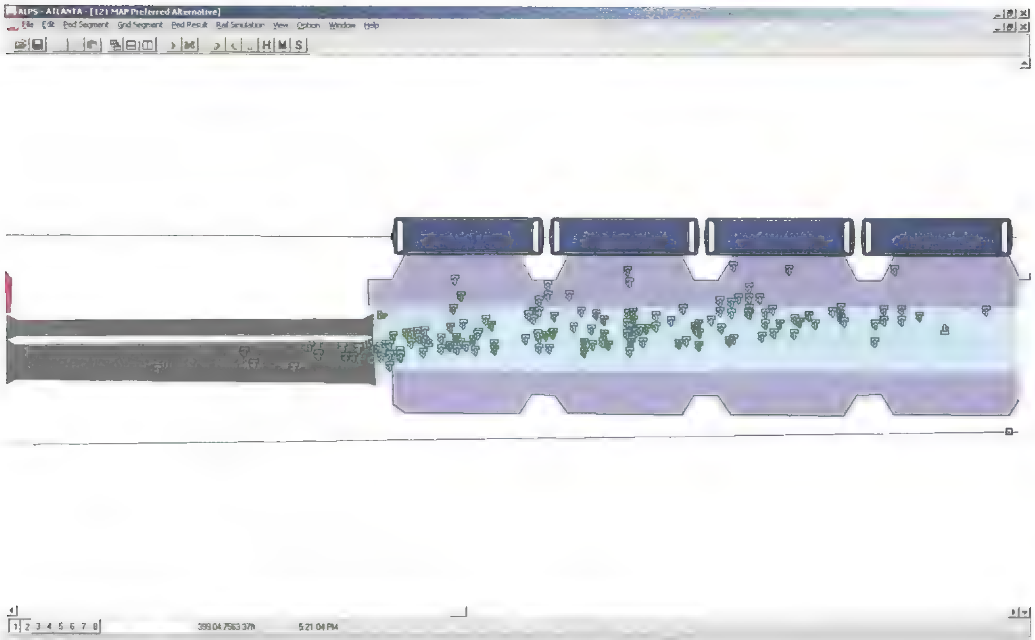


Figure E-5. Heavy demand station with alighting surge flows to vertical circulation system.

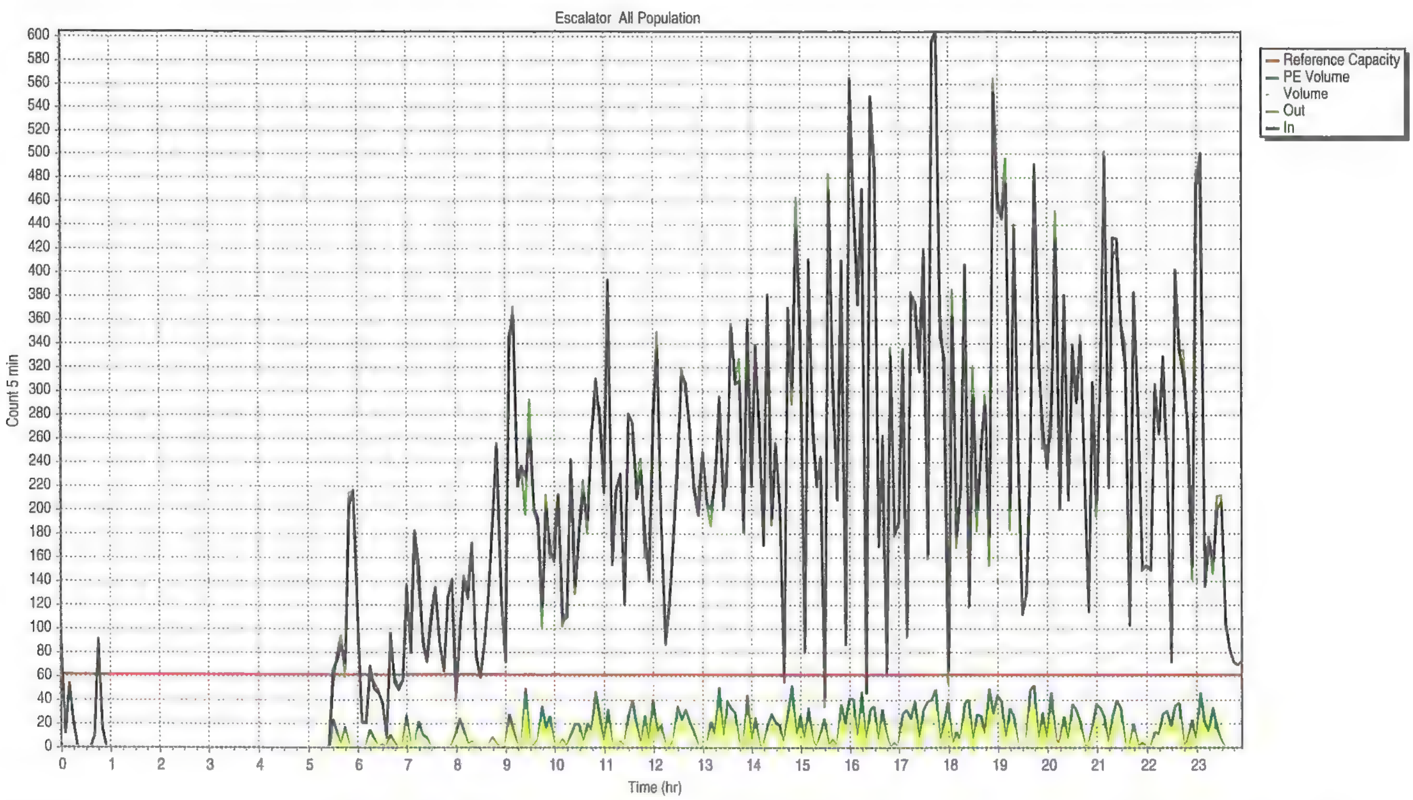


Figure E-6. Dual escalator demands for an APM station where most passengers alight to reach baggage claim through vertical circulation.

concourse will determine the unique demand patterns by time of day; and

- At stations serving specific landside facilities such as rental car facilities, the patterns of mode split with respect to car rentals and returns by time of day, thereby changing the distribution of boarding and alighting demands.

Operational Impacts

Simulation models have other application aspects that can be very beneficial to analyzing the station facilities, vertical circulation elements, and short-duration ridership demand loads. Operational anomalies are common in the real world, and airports in particular must be continually adjusting to variations in the flight schedules as weather, air traffic, and equipment malfunctions change the patterns of demand on the APM system.

The nature of simulation methodology allows random effects to be studied in detail, as opposed to the deterministic, static nature of most spreadsheet models. This stochastic analysis capability can be important when station capacity limitations are a concern. The processing power of simulation models allows randomization of, for example, the flight schedule database in terms of aircraft arrival times, which can substantially change the peaking patterns at APM stations. Having a randomized series of model runs with a suitable sampling of the distribution of peak demand conditions allows a more real-world assessment of the actual design capacity that should be defined for the station elements.

Simulation models also allow the study of operational impacts resulting from service disruptions of the APM system. Even in the planning phase of the project, it can be important to assess the effect of failure-induced passenger accumulations within the APM stations. For example, if train operations are stopped for an extended period during a critical time of the day (e.g., 30 minutes without service during the peak hour of the day), then a station's boarding platform may completely fill with people. Once system service is restored and trains with a completely full passenger load begin to arrive, initial operation must address the effect of arriving trains discharging unusually large numbers of alighting passengers onto the station platforms that are already full of waiting passengers. Simulation models can assist with studies of such failure recovery operating conditions.

A third aspect of airport operations that is driven by policy decisions is that of allowing luggage carts into APM stations, and in some airports allowing passengers to take them onto the APM system. Increasingly, planning studies are being tasked to evaluate the implications of luggage carts being taken into the station area, on the trains, and through the entire APM system. Such studies can greatly benefit from full simulation modeling of the passenger flows at stations as well as on trains when the models include the greater space that luggage carts require for a percentage of passengers. Luggage cart aspects can also benefit from simulation model tests of different random mixes of such large space-claim conditions.

In summary, simulation models can be used to not only test the operational impacts of random effects (e.g., flight schedule/air passenger patterns) and variations of luggage cart space claim under normal operating conditions of the APM system, but also under equipment failure-mode operating conditions.

Train Performance Analysis

The performance analysis of the APM system automated trains/vehicles is an area of study to which simulation models are commonly applied, even in a planning-level study. Although a full range of APM technologies is not necessarily studied in early planning work, a generic baseline technology is frequently defined for analysis purposes. The following aspects of the APM system are usually the focus of the performance studies:

- **Acceleration/jerk and operating speed**—These elements of train performance are included in most simulation models of train performance. In a planning-level analysis, the most important of these is the operating speeds along the planned alignment of APM system. Some approximation of the guideway alignment, configuration, and station locations, and in particular the curve radii that are possible given the alignment, are typically the controlling factors in the maximum operating speed at which the train can progress along its route. Figure 7 shows a graph of the train performance results for a given link (defined as the guideway between sequential station stops). In the particular simulation mode shown, the allowable operating speed is shown in accord with the guideway geometry constraints and other operating considerations. The train's acceleration/deceleration response to the allowable speed compensates for the trailing end of the train clearing the reduced speed zone before acceleration occurs to a higher speed.
- **Power and energy**—The APM vehicle propulsion system and the related train resistance parameters are usually part of the input data for the simulation model. When a generic baseline APM system is defined for planning study purposes, the simulation of train performance provides power and energy consumption estimates that are very useful to establish capital cost and O&M cost estimates. Figure E-7 also shows power consumption for train progress along the selected link.
- **Round trip time**—The most important end product of the performance simulation is the determination of the round trip time for the specific alignment, guideway configuration, and station locations. The round trip time is used in

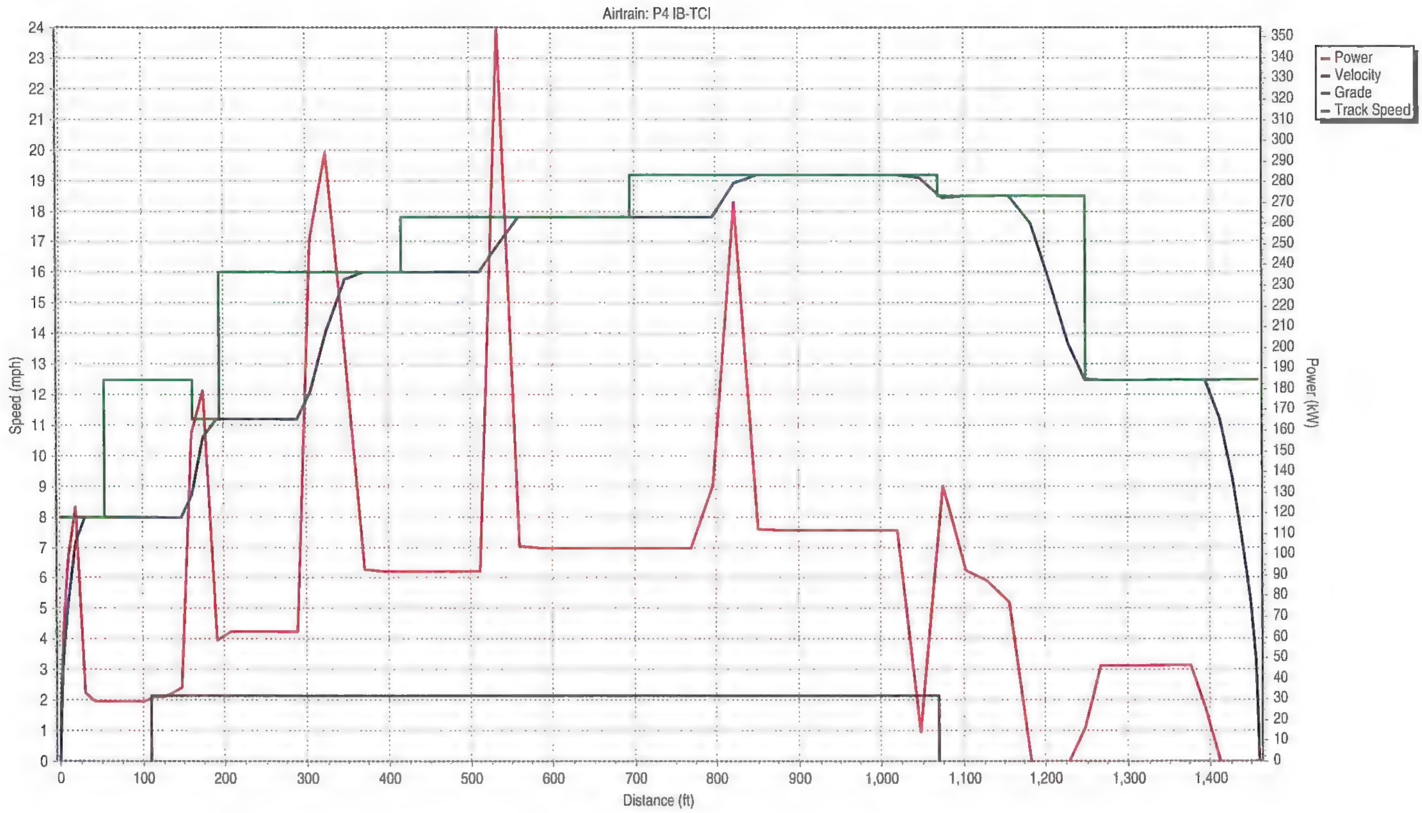


Figure E-7. Train performance simulation station-to-station link results.

the planning process to determine the operating fleet size and the throughput capacity for a given number of trains/vehicles in service.

System Operations Analysis

The final area for which simulation models are often used in the planning phase of study concerns the analysis of the whole system's operations. Although some aspects of system operations are not necessary to address in planning levels such as for master planning studies, higher levels of advanced planning do require this analysis when APM projects are reaching a program definition stage with budgetary cost estimates, programmatic sizing of facilities, and protection of right-of-way.

Given below is a brief overview of system operational features that advanced simulation models are capable of applying within the analysis process:

- **Testing of supervisory control functions**—There can be some APM operational conditions that require certain constraints and management functions to be imposed by the automatic train supervision system. When this aspect of automated operations is recognized as important during the planning of the system, then there can be substantial benefit to a simulation-based assessment of these ATS functions. Some examples are headway management routines that continually work to even out headway perturbations following operational interruptions, and "station-ahead-clear" controls that prevent a following train from leaving a station until the train in front has cleared the station ahead.
- **Emulation of moving-block train control systems**—The operational benefits of moving-block control systems has resulted in a whole new set of train control products to be offered in the APM market place. The ability to operate trains closer together, compressing headways to absolute minimums, can be a matter of interest, even during the planning phase of the project. Figure E-8 illustrates the way that the simulation model continuously calculates the minimum safe stopping distance of each train as a function of its operating speed at each point in time. In the figure, the colored target point in front of the train represents the moving-block protection, which when encroaching on a train ahead would cause the following train to slow down.
- **Demand responsive dispatch**—The advancement of PRT technology to the first implementation at an airport brings the consideration of this operating mode to the forefront of planning studies. The simulation of the very dynamic operating conditions inherently imposed by PRT application requires the emulation of a demand-responsive dispatching of vehicles—meaning that vehicles are not sent into service until there is a passenger demand imposed from a specific

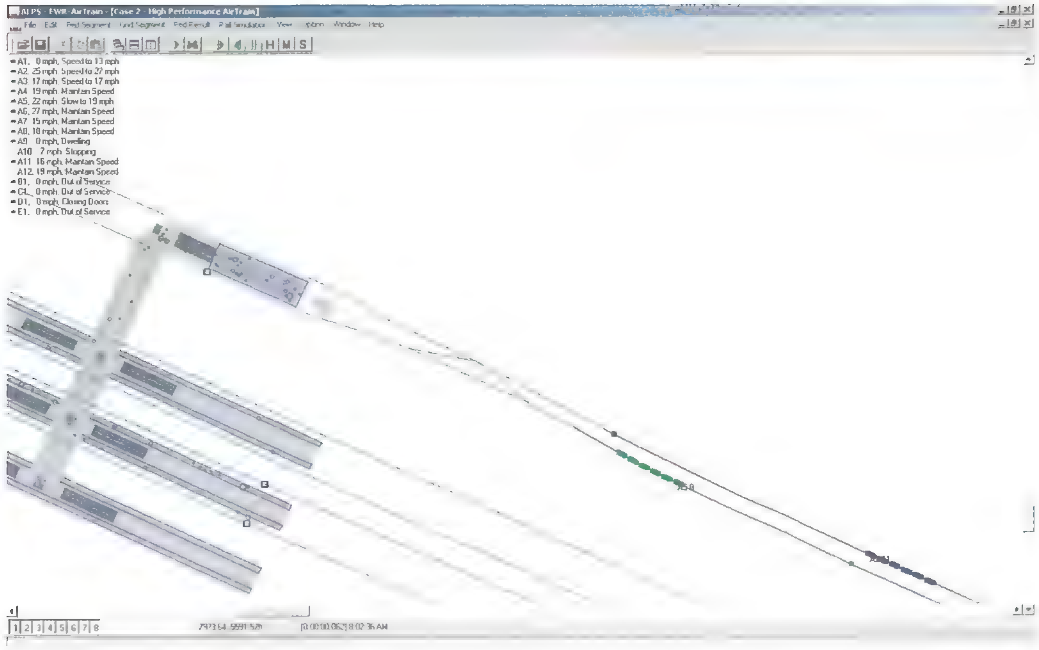


Figure E-8. Simulation of a moving-block train control function.

origin station to a specific destination station. A second aspect of complexity for the simulation model to analyze is the management of empty vehicles, including their placement in strategic storage locations in or near the stations where higher future demand is anticipated.

When complete APM system operations are simulated, the model allows a rigorous testing of changes to system capacity through variations in train performance, system alignment/configuration, and train size. For simulation models that also combine the system operations with the modeling of ridership and station passenger flow, these operational changes can also be used to evaluate the resulting impacts on level of service and localized overload conditions within the APM station facilities.

Most importantly, the system operational simulations over a 24-hour day provide important data such as vehicle operating miles and operating hours and power consumption. Simulation models are also very useful for conducting optimization studies of the operating fleet size. While it is true that a full operational analysis is not required for the planning of many APM systems, for the more complex dynamic conditions—such as with the demand responsive dispatching of vehicles—the simulation modeling of complete APM system operations is very important.

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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